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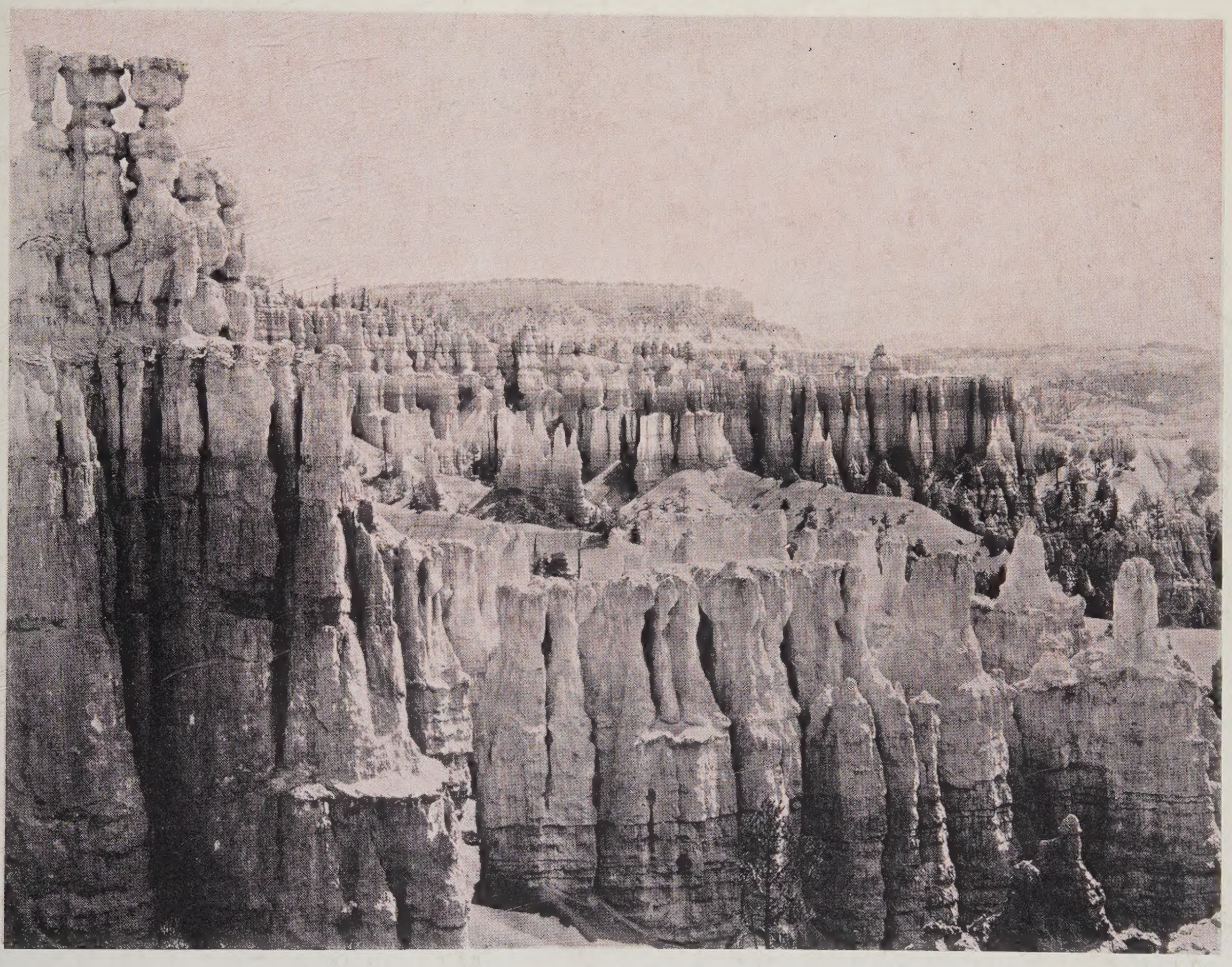

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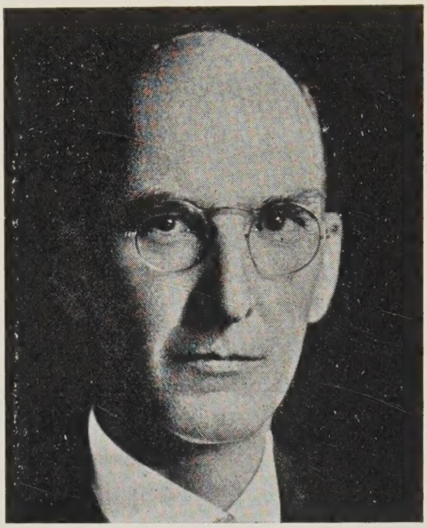
A Message From the President

To the Institute Membership—

All of us who grew up on farms will recall the occasions when trimming and pruning of the apple orchard became necessary. Dead wood and "suckers" had to be trimmed out, and the trees generally "tidied up." Some immediate crop was sacrificed, but if judiciously executed the process was salutary and in the end resulted in more shapely and accessible trees and more and better apples.

Some such process as this, I hope, is what is happening today to our American social and industrial system. If carried out with judgment and restraint the final results should be beneficial. Certainly a somewhat more orderly and controlled industrial organization, for better or worse, seems to be gradually emerging, and if lack of restraint does not result in destruction of the "orchard" we all at least may hope for "more and better apples."



Joseph Allen Johnson
A.I.E.E. President, 1934–35

In this "tidying up" of our social system the engineering profession as a whole, and the Institute in particular, must participate if they are to contribute to, and share in, its benefits. In fact several movements to this end are already under way or being considered. Among these are: (1) the Institute's new coördinated publication policy, (2) proposed "Junior" grade of Institute membership, (3) Engineers' Council for Professional Development, (4) reorganization of American Engineering Council, (5) Coördinating Committee of Engineering Societies, (6) proposed National Advisory Board of Engineers, (7) licensing of engineers by various States, (8) State societies of licensed professional engineers, and (9) proposed National Society of Licensed Professional Engineers.

In this seeming welter of developments and proposals, with various and apparently conflicting purposes and motives, it is difficult to see clearly what courses the individual engineer, on the one hand, and the existing professional engineering societies, on the other, should pursue. Which of these movements have objectives consistent with those of the Institute and other similar societies, and which have not? If some of these objectives are different from those of the Institute, are they therefore objectionable, or are they in themselves legitimate and desirable?

In several of these movements one or the other of 2 objectives seems to predominate. One of these is the *professional* advancement, the other the *economic* advancement of engineers. To what extent are these objectives mutually antagonistic and to what extent sympathetic? Can both be consistently promoted by a single organization or consistently supported by the same individual?

During the coming year your president will be obliged, perforce, to do considerable analytical thinking in these matters, and with ye editor's kind coöperation he shall hope to do some of it "aloud," so to speak, in Electrical Engineering. If you should happen to agree with thoughts he may express, it would be helpful if you occasionally would drop him a line to that effect, and similarly contrariwise. Possibly by thus thinking together we both may be enabled to steer a truer course through the mist.

In anticipation therefore of occasionally writing you further on the above and perhaps other topics, and of occasionally hearing from you in reply, I am

Yours faithfully,

J. Allen Johnson

The Institute on Its 50th Anniversary

By J. B. WHITEHEAD, President A.I.E.E. 1933–34

TWO outstanding characteristics of the Institute's work have been especially striking during my term as president. The first is the high degree of efficiency and the smooth operation which characterizes the chief feature of the Institute's work, *viz.*, the reception, the consideration, the publication, the presentation, and the discussion of technical papers. The enthusiasm, energy, skill, and competence with which our technical committees function is evidently based upon a combination of profit from experience, and devotion to the Institute and its ideals. Changes of personnel, changes of administration, cannot disturb the smooth functioning of an organization perfected over the years and always animated by the highest professional spirit. Supported by an equally efficient and devoted headquarters staff, it is not to be wondered at that an incoming president, timorous with uncertainty, and dreading the necessity for the study of detail, should experience a feeling of immense relief at the realization of how large a proportion of the Institute's work can go on without his attention and probably be the better therefor.

My second vivid impression is related to that rather large group of questions which come before the board of directors of the Institute, which do not always fall naturally within the normal scope of either our technical or our general committees, and which, therefore, necessitate factual examination, discussion, and, of course, ultimate decision. Now questions of this character are characteristic of all large organizations, and I would not call especial attention to them in our own case were it not that many of these questions originate within our own membership, and apparently because of failure to recall first, the basic purposes for which the Institute exists, and second, the provision already made by the Institute for the answering of them. It is this latter aspect of these questions which has struck me so forcibly, and which leads to the principal theme of this brief address. In it I propose to state anew the purposes and ideals of the Institute as set forth by its founders and so carefully nurtured and revered through these 50 years, and to point out certain dangers of departures from them, as yet not serious, but whose manifestations, if allowed to pass unnoticed, may increase to threatening proportions.

The Institute's Tangible and Intangible Assets

First, however, and in order to indicate that my dominant feeling at this time is a hearty concurrence in the happy spirit of our anniversary celebration, and my confidence in a continuously expanding high future for the Institute, I ask you to review with me very briefly the grounds upon which, in our splendid anniversary issue of Electrical Engineering, in the celebration meetings in the various Sections and Branches, and in this culmination meeting at the convention, we are basing our joy in the 50th birthday of the Institute. The answer is easy and is found at once in our record of accomplishment.

We may conveniently consider this record in terms of both tangible and intangible accumulated assets. Our material or tangible assets are obvious. Our contributions to the advance of the electrical art in ever-growing volume, as represented in the published file of our Transactions; our continuous growth in membership only temporarily retarded at present; our unimpaired services to the membership in all phases of our work, even during the years of business depression; and finally, the distinguished list of names of those great engineers and scientists who have heartily participated in the Institute, and helped to build its high professional standards. These, I say, are some of our tangible assets. Together with others, they have been reviewed in detail in our recent publications and meetings, and I need not attempt to add anything to these reviews. Certainly they are sufficient grounds upon which to base a happy celebration.

However, I take it that it is eminently appropriate, in an anniversary year, to review also our intangible assets. These are the spirit which animates us, the traditions that guide us, and our faithfulness in carrying out the vision of the founders. Can any one doubt that the glorious record of achievement, strength, and unity, with which this record is continued from year to year is due to these intangible assets, to our unswerving adherence to the principle laid down by the founders that we exist primarily "for the advancement of the theory and practice of electrical engineering. . .and the maintenance of high professional standing. . . ." These latter phrases are in quotation marks. They are taken from our constitution. I cannot express too strongly my conviction that the remarkable growth and success of the Institute is primarily due to the single-mindedness with which successive administrations have adhered to the fundamental purposes of our existence, thus clearly stated.

Institute Interest in the Individual Engineer

The Institute has also indicated from time to time its concern for the "professional development" of the individual engineer. The question of the measures which should be taken in furtherance of this concern has occasionally caused differences of opinion among our membership. The meanings of words are always elastic and subject to special interpretation as related to the interests of those using them. To the more conservative of us, it has appeared that the Institute can best accomplish this purpose in the setting of high professional standards, in the maintenance of a high quality of technical papers

The president's message, presented at the A.I.E.E. summer convention, Hot Springs, Va., June 25–29, 1934. *Not published in pamphlet form.*

and discussions, in providing ample opportunity for younger members to hear and participate in meetings, to reward initial contributions, and to indicate desirable educational processes. To others, happily in my opinion relatively few in number, this avowed concern of the Institute for the professional development of a member has been interpreted as meaning an obligation to reach out if necessary into questions of semi-political and other controversial character often involving only the well-being of local engineering groups or even individuals.

As you know the Institute has adhered to the more conservative of these policies. That it has been actively interested in the professional welfare of its members is shown by its educational and other committees concerned with professional status, in its support of the splendid Engineering Societies Library, in the copious general matter in the monthly journal, and especially in the fine program of the Engineers' Council for Professional Development.

Does this mean that the Institute is not interested in the economic and social well-being of its members? By no means. It is very deeply interested in such questions and engages actively though indirectly in measures for their solution. It does mean, however, that the Institute has always felt that these activities lie outside the traditional constitutional purposes for which it exists, that questions of economic and social status usually pertain to the engineering profession as a whole, rather than to the electrical group only, and finally, that the Institute's concern and participation in such questions should be accomplished through joint agencies representative of all branches of the profession. As you know, the Institute participates actively in a number of such joint organizations, committees, and boards set up from time to time for discussion and action in matters of common interest to the entire engineering profession. What is not commonly understood, however, is that in practically every one of these cases, these agencies have been set up for the handling of just such types of questions as those we are considering, which seem to fall outside the traditional functional purposes of the separate founder societies, could not be effectively handled by any one of them, or all of them acting separately, and which, if so handled, would undoubtedly divert attention and financial support from their respective technical and strictly professional activities. Moreover, as evidence of the importance attributed by it to these matters of joint concern, the Institute has consistently assigned to these duties its most able and experienced professional talent. Our representatives on these joint agencies are commonly our presidents, past presidents, and past and present members of the board of directors. The Institute is, in fact, very deeply interested in both the professional and the economic status of the individual engineer and has always made ample provision for discussion and action on all public questions involving his well-being. This clear separation of questions of pure technical and professional character, as the Institute's first concern, from those involving the economic and social status of individuals or groups, and the provision which has been made for the separate adequate handling of each, are to my mind fine evidence of the high professional spirit which has guided the Institute through the years, and its consequent success.

Actions on National Questions

In order that you may understand the grounds which lead me to feel that this survey of old principles is desirable at this time, I will review briefly our action on several questions which have arisen during the past few months. These questions have emanated from our own membership, sometimes from individuals, and sometimes in the form of resolutions by individual Sections.

It will be recalled that in the inauguration by the Government of aggressive methods for fighting business depression, every organization of whatever character and so including the Institute, was asked through the mail to subscribe to the principles of the N.R.A. and to follow this up with the submitting of a code regulating the organization's activities. There was much immediate individual comment among our membership in opposition to any attempt to set up a code for engineers of the type proposed by the N.R.A., and no voice was heard in favor. American Engineering Council, one of our most effective joint organizations with other societies which exist exactly for the purpose of investigating and advising on such questions, proved itself here as usual wide awake, developed further information, and conferred with counsel of N.R.A. as to advisable action for the national engineering societies. It was learned promptly that the provisions of N.R.A. were not intended to apply to scientific and professional bodies. The Institute received similar opinion from its own counsel. The matter appeared to have been promptly settled by existing agencies, without the necessity for more than passing consideration and action by the board of directors. Up to this point, therefore, this is an admirable example of the effectiveness of our organization, and of our connections for the handling of questions extraneous to our normal functions.

However, as time proceeded, it was found that this clear separation could not be extended to certain branches of the construction industry in which many engineers were employed and that a code was being prepared which, in certain of its aspects, appeared likely to be regulatory in its effect upon certain classes of engineers. Several protests were received from both individuals and Sections with recommendations that the Institute should combat actively the setting-up of such a code. No specific recommendations of the action to be taken were made, nor was it immediately obvious as to how members of the electrical engineering profession were to suffer. In other words no conspicuously advisable action was indicated. However, it was soon realized that again in American Engineering Council and in other joint agencies with our sister societies, the matter was being discussed, apparent inequalities were being ironed out and, as time has progressed, it appears probable that if the engineers' construction code is adopted at all, it will be of very limited application, and may not affect the greater numbers of the mem-

berships of the founder societies, including, of course, our own. Again, in this case, it will be seen that the handling of the question and its solution have been practically automatic under existing agencies.

Another question which has occasioned wide concern, and properly so, is that of various disparities between the compensations of young, trained engineers and of ordinary labor, under the P.W.A. and the C.W.A. Here was an obvious injustice arising under Government regulations, and protests from somebody were obviously in order. American Engineering Council was again on the job, with a thorough examination of the facts, protests to proper governmental quarters, a final uncovering as to where the principal trouble lay, and suggestions as to how it might be corrected. The accumulation of facts and subsequent study of these questions require time and effort such as may not commonly be asked by the Institute of the members of either its technical or general committees. American Engineering Council, however, has been established primarily for just such purposes and in this, as in many other cases, has succeeded admirably.

Another highly important question involving the engineering profession, and which cannot yet be said to have been satisfactorily answered is that of the encouragement by the Government for the establishment of power plants under municipal and federal control which shall be in direct competition with others privately owned and in efficient operation. Suggestions that this is a matter for the Institute's concern have not been as frequent in this case, but they have not been entirely wanting.

Naturally the Institute is keenly interested in the many possible injustices of such a policy. However, it must be apparent that the Institute could not take an aggressive part in combating these measures without finding itself in a rapidly expanding program of public discussion outside its proper field with consequent demands upon the expert services of its members and committees, the expenditure of money, all to the serious detriment of normal programs of technical activities. In fact, the mere collection and analysis of information for the effective discussion of questions of this character would entail time and effort far beyond the normal voluntary services offered by its members to the Institute, and could not indeed be accomplished except through analytical, professional study involving the whole-time services of competent men. Yet the board of directors has been memorialized by more than one Institute Section with proposals that we should take active measures for the prevention or combating of the Government's action. What then was the proper course for the Institute to pursue? Its action was prompt. It referred the matter to American Engineering Council, and in the protracted discussions within Council of this matter, a very broad position in which we concur, in the form of dignified protests to proper Government agencies, has been taken.

In passing I may point out how very effective in this series of matters have been the services of American Engineering Council and how very important a part it has played in relieving the Institute of direct action in a variety of questions in which it is deeply interested. The Institute is also deeply indebted to United Engineering Trustees, to Engineering Foundation, and to several other bodies with which it is jointly associated, in the handling of many other matters of wide importance to the engineering profession, and which cannot be satisfactorily handled by the respective member societies. A joint Coördination Committee of Engineering Societies is at present reviewing the possibility of uniting into one general body these several important organizations. Its first report has just been submitted to the respective governing boards. No doubt a well considered conclusion will be reached from these discussions. If I may be permitted to inject a personal opinion, it has seemed to me that the respective spheres of American Engineering Council, United Engineering Trustees, Engineering Foundation, and other similar joint bodies are so diversified in scope, intensity, and location of their activities, that even if they were united, new subordinate bodies or committees equivalent to the present organizations would have to be set up. Certainly if an additional central body, with headquarters in New York, were set up, substantial further expense would be involved. Whatever may be the ultimate recommendation in this matter, it is my conviction that American Engineering Council must, for our best interest, be maintained in the high state of usefulness and efficiency, which has characterized it in recent years.

The Institute Has Due Cause to Celebrate

But I must not close on a serious note. The things which I have mentioned need cause no great concern and are far from being uppermost in my mind. Our thoughts and feelings are attuned to our anniversary celebration. And well they may be. A splendid past, no vain regrets, a healthy and efficient present in hard times, and a brightening prospect for the future, can cause only satisfaction and rejoicing.

As I approach the end of my term of office I find that I have 2 most vivid impressions. The first is of the fine morale, enthusiasm, and efficiency of our working committees, the vertebræ of our professional backbone. To chairmen and individual members I am happy to extend congratulations and thanks on behalf of the Institute.

Equally impressive is the recollection of my series of visits to 19 of our Sections. It was an inspiration to find everywhere the high spirit of our central purposes and methods reflected practically without question; enthusiasm and devotion to the Institute and its ideals; local provision for effectively bringing the work of the Institute to the membership; active recruiting committees. In fact, in addition to its other blessings the Institute seems to me to enjoy excellent health in spite of its 50 active years.

May I close with a brief but sincere personal word of thanks and deep appreciation to the board of directors, to the membership of all committees, to all Sections and Branches, particularly to those I have been able to visit, and to the headquarters staff, for their constant support and many courtesies.

Toward the Making of a Profession

An illuminating analysis of the reasons for and obligations of a profession, and in particular of the A.I.E.E.

By
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MEMBER A.I.E.E.

President, Case School of Applied Science, Cleveland, Ohio

IN THIS paper an endeavor will be made to indicate not only the contributions of the Institute toward the making of a profession within its own sphere, but also to the growing and evolving part which professions in general are assuming in the manifold complex of functional units which make up the organism of a modern society.

Of professions there are many kinds—open professions like music to which any man may aspire within the limits of his God-given talent, and closed professions like medicine which may be entered only by a straight and narrow legal gate; individual professions like painting, whose devotees refuse to be herded into an organized body, and group professions like law, whose members constitute a special class in society; private professions like authorship, and public professions like journalism; artistic professions like sculpture which invite imagination, self-expression, and technical professions like surgery which impose the most rigorous of disciplines; localized professions like dentistry, and expansive professions like diplomacy; professions like social work which aim only at amelioration and professions like arms which achieve their ends through destruction. These diverse patterns may seem a mass of confusion and mutual contradictions; not so, for through all of them there runs a common warp on which each profession fashions its distinctive woof.

A profession in the corporate sense is a guild organized for self-government, and one limiting its admissions and recognition by high standards of technical competency, ethical purpose, and social accountability. A profession is the corporate trustee of a distinctive body of organized knowledge, a science, and of a distinctive body of techniques and skills, an art. A profession is a body of persons who deal with problems that have social significance and lie on a high intellectual plane, in a relationship of individual responsibility. A profession is a body of persons with an articulate conception of social function and duty, which includes but transcends the specific duties and tasks of individuals, invests them with a significance beyond the expediency of a moment, and lays upon its members the duty to consider their acts on a long-range time scale, and a wide scale of social consequences.

Essentially full text of an address presented at the A.I.E.E. summer convention, Hot Springs, Va., June 25–29, 1934. *Not published in pamphlet form.*

Evolution of Professions

The obligations of a profession grow out of its origin and evolution and cannot be considered as things apart. Professions have evolved from 2 types of parent stock, priestcraft with its magic and mysteries reserved to the initiate, and the corporate guilds of merchants and craftsmen which arose in the late middle ages. Engineering, without dispute has grown from the latter stem; the traditional learned professions from the former.

The guilds developed in the gap between feudalism and the centralized state. In a period of disintegration and remaking of the social order, before national governments had taken over judicial powers or cities their familiar police powers, commerce could exist only by mutual policing and protection, and trade only by self-imposed control. The far-flung argosies and caravans of merchants had no embassies, consulates, navies, and armies from which to demand protection. For the crafts, mutual regulation of hours of labor, terms of apprenticeship and quality of workmanship was the only alternative to competitive anarchy. The religious philosophy of the times favored the idea. The middle ages regarded society as a commonwealth divided into divinely ordained functions, where individualism was to be frowned upon and group activity favored.

When the cities began to consolidate their public powers, the guilds were already strongly entrenched. The cities recognized the priorities of the guilds, confirmed their privileges and monopolies and gave them a corporate part in the machinery of government. In London, the so-called "livery companies" preserve to this day these traditional prerogatives. The largest of the 3 federated educational units which make up the Imperial College of Science and Technology is the "City and Guilds Engineering College," whose endowments were set apart, by public direction, from the funds of ancient craft and merchant guilds, as the nearest modern equivalent to the old-time encouragement and regulation of apprenticeship.

In addition to regulating working conditions, quality of workmanship and apprenticeship, the guilds commonly required their members to contribute periodically to a fund for relief and burial of indigent craftsmen, to participate in certain religious observances, and to honor certain festivities and pageants. You may find all these features dramatically portrayed in Wagner's opera "Die Meistersinger." Most of them are perpetuated with a striking persistence in our own group of professional bodies. We engage in various forms of self-government; we associate ourselves in certain functions with cities, states, and nation; we maintain an employment service, and when occasion demands,

a relief service; The American Society of Mechanical Engineers included a formal religious service and a historical pageant in its late jubilee; and we are today celebrating our own golden anniversary.

Social Relationships

Under this time-honored tradition, the state accepts the actual or potential pre-existence of professional bodies, grants them public charters, grants or confirms more or less tangible monopolies and privileges, delegates certain police powers and recognizes their autonomy, in consideration of which each profession engages to admit only men of proved competency, to scrutinize the quality of their work and to protect the public against bungling and extortion. The admission of persons not strictly qualified to a professional body on a courtesy basis, or the winking at business piracy in any form or degree under the cloak of professional activity, is by its nature a breach of public trust.

The occasion which calls for professional service is often a human emergency, aggravated by emotional stress, under which the layman cannot be trusted to judge for himself of the quality of the service proffered. The same is true only in less degree in public emergencies. Under these circumstances the legal principle of *caveat emptor*—let the buyer beware—which holds in a purely commercial transaction breaks down. The public rightly places the burden of guaranteeing at least minimum standards of competency and ethics on the profession itself, and in return protects it from incompetent judgment by lay critics.

Before turning to a consideration of the distinctive professional qualities and services of our own body, it will be appropriate to recapitulate the standards by which the genuineness of professional status may be tested and its qualities appraised:

Attributes of Individual Professional Status

1. *A type of activity*, involving:
   a. A high degree of individual responsibility.
   b. The handling of problems of high social utility, on a high intellectual plane, under a code of ethical responsibility.
   c. The use of skills and techniques not commonly possessed.
2. *A motive of service*, distinct from that of profit, which differentiates professional activity from ordinary business.
3. *A motive of self-expression*, which implies a joy in one's work, imposes an austere standard of self-criticism, and leads to a single standard of workmanship—one's best.
4. *A conscious recognition of social duty*, to be fulfilled among other means by:
   a. Sharing advances in professional knowledge.
   b. Guarding the standards and ethical codes of one's profession and enhancing it in the understanding and esteem of the lay public.
   c. Rendering a fair share of gratuitous service, either to needy persons or for the public good in return for special advantages of education and status.

Attributes of Group Professional Status

1. *A corporate trusteeship* of a body of advanced knowledge (a science) and of a body of special skills (an art) held as a common possession and to be extended by united effort.
2. *An educational discipline* of professional aims and content, in which the professional body has a share of directive responsibility usually associated with gradations of title or rank to mark the progress of individual attainment.
3. *A standard of qualifications* for professional recognition, based upon:
   a. Character, worthy of public trust in emergencies.
   b. Training of adequate degree.
   c. Competency, both technical and social, to determine the "whether, when, and how," of professional problems.
4. *A standard of conduct* in relation to:
   a. Clients, based upon professional integrity.
   b. Colleagues, based upon regard for mutual rights.
   c. The public, based upon social and ethical intelligence.
5. *A formal recognition of status*, by one's colleagues or by organized society (not common in the artistic professions).
6. *An organization* based upon common interest in advancement of the profession and on social duty, rather than economic monopoly.

Since a profession must so largely govern itself, it is assumed to maintain certain codes:

1. A code of qualifications governing admissions.
2. A code of ethical practices in relations with clients.
3. A code of professional honor in internal relationships.
4. A code of public obligations.

Responsibility of Membership in a Profession

The obligations of a profession are so much a matter of attitude that codes alone are not sufficient to sustain them. Equal importance attaches to the state of mind known as professional spirit, which results from associating together men of superior type, and from their common adherence to an ideal which puts service above gain, excellence above quantity, self-expression above pecuniary incentives, and loyalty above individual advantage. The professional man cannot evade the responsibility to contribute to the advancement of his group. His skill he rightly holds as a personal possession, and when he imparts it to another he rightly expects a due reward in money or service. His knowledge, however, is to be regarded as part of a common fund; hence the obligation to publish researches and to share advances in professional practice. If his abilities do not permit him to do so personally, he can at least pay his debt by contributing financially to the dissemination of the works of others.

Many engineers need to be warned away from too short-sighted an attitude in this matter. There are doubtless thousands of us to whom the immediate tangible value of the publications of a professional society is much less than their cost, yet when one pauses to consider the magnificent body of knowledge which has been accumulated as a common heritage the tax levied in the form of professional dues assumes almost negligible proportions. Research is indeed one of the most potent means of enhancing a profession's prestige, as the advance in the standing of the medical profession in the last 3 decades so clearly testifies.

Professional status is therefore an implied contract to serve society in consideration of the honor, rights, and protection society extends to the profession. Through all professional relations runs a 3-fold thread of accountability to colleagues, to clients, and to the public. Business moves toward the professional area as its management passes from proprietors to a distinct administrative caste with little or no immediate stake in the profits of

trade. In so far as the rewards and status of this caste rest on long-range prosperity rather than quick returns, it is able to maintain the attitude of accountability to investors, workers, customers, and the public, which is the irreducible element in professional standing. Whatever of social loss has resulted from the blurring of the engineer's personal status, has been largely offset by what he has contributed as an administrator to the professionalizing of industry.

The Institute's emphasis on the several threads which make up the common warp of all professional activity has been unequal, to be sure, but its fidelity to the spirit and ideals has been notable. Considering the youth of the profession, some selection among the many aspects of a mature professional life was inevitable and this selection has been marked by a discriminating wisdom.

The Institute Is Broad in Scope

The inclusiveness of our membership has ranged us among the democratic rather than the aristocratic professional bodies. The scope of our interests has been wide enough to avoid an undue fragmentizing of personnel and activity. Among its sister organizations the Institute is notable for its success in assimilating the research scientist, on the one hand, and the industrial executive, on the other, into the common life of the profession. The one has been immensely fertilizing intellectually, and the other has advanced the frontier of professional service and standards in the business world. To it we may properly ascribe much of the high sense of social obligation which has characterized the electrical industries as a group and the leadership exercised by their officers in advancing movements for the public good. As our profession is more closely integrated than almost any other with corporate activity and is perhaps least involved in purely personal emergency services, there has been only moderate need to guarantee to the public the competency and character of our men. Our unique mission has not been to draw professional lines sharply, as in medicine, but to infuse industrial activity with professional tone, with a high sense of trusteeship for the advancement of science, and with the standards of accountability to investors, employees, customers, and the public which professional service entails.

Contributions of the Institute to Education

The ideal of educational service to young engineers was paramount in the organization of the Institution of Civil Engineers in Great Britain, which has been the prototype from which many of our traditions were drawn. To this ideal the A.I.E.E. has given both generous and constructive support. There has been far more concern that methods of recruitment and training should be such as to provide an adequate personnel for the fast-growing industry, than to protect any monopoly interest of men already established in the profession. The Institute has encouraged and not policed education. By giving the student a real part in the activities and associations of a professional body, it has done what the school alone could not do. The work of our beloved past president, Charles F. Scott, in articulating the interests of the schools, the industries, and the Institute, as instruments for the education of the electrical engineer, is itself an epic in the history of professional life in America.

The great work of stimulating engineers to a continuation of their serious education after the period of schooling has ended is the most important task immediately before the profession. Leadership in this field has been conspicuous in the electrical industries and it is but natural that members of the Institute have taken a conspicuous part in shaping the objectives of the Engineers' Council for Professional Development.

The Many Other Contributions of the Institute

The chief glory of the Institute has been its contributions to the making of the science and art of electricity and to establishing the new technique of progress to which the philosopher Alfred Whitehead alludes in his much quoted statement:

> "The greatest invention of the 19th century was the invention of the method of invention; . . . it is that which has broken up the foundations of the old civilization."

In the traditional crafts—the making of metal objects, of pottery, of textiles and the like—the art came first and the science long after. The tempo of progress by unaided evolution was exceedingly slow. The greatest invention of the ancients, the art of writing, is believed to have required a thousand years for its achievement.

In modern times, the old order of crude invention followed first by slow refinement and ultimately by research has been reversed and the tempo of progress vastly accelerated. Savery and Newcomer preceded Carnot by 125 years. Faraday's great researches on electromagnetic induction were but 35 years in advance of Gramme's generator and 54 years in advance of the Edison bi-polar machine. The mysteries of the "Edison effect" of 1883, revealed by Richardson's researches on emission 20 years later, became fruitful almost immediately in Fleming's 2-element valve and De Forest's 3-element audion.

Greater than any material resource or any endowment has been the Institute's intangible contribution to this science and art, through the stimulation of research, the recognition accorded to scientific disclosure, the dissemination of a literature of priceless value without reference to its commercial possibilities, the award of honors for notable achievement, the spur of the rostrum and the forum, and the emulation of great men engendered among young engineers. It is to be doubted if the roster of any engineering organization of equal youth has been as rich in the names of great investigators and creative inventors.

The formalizing of codes of professional courtesy, honor, and ethics has been to the Institute a sec-

(*Continued on page 1172*)

Fundamental Laws of Photoelectricity

By A. L. HUGHES
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Although the present amazing variety of applications of the photoelectric cell has been developed entirely during the past decade, the photoelectric effect was discovered during the nineteenth century. This article gives a brief account of the fundamental laws of photoelectric phenomena and their theoretical significance; it is the eighth of a series of special articles prepared under sponsorship of the A.I.E.E. committee on education, for full details of which see p. 238 of the February issue.

PHOTOELECTRICITY comprises that part of physics dealing with the electrical effects produced when light, or more generally, radiation, falls on matter. The photoelectric effect, which was discovered in the last century, received little or no attention except from physicists until the last decade, when an amazing variety of applications of photoelectricity made the photoelectric cell almost a household word. Essentially, the photoelectric cell is a device that delivers an electric current when light falls upon it, and, in general, the electric current is proportional, or nearly proportional, to the amount of light falling on the cell. Thus any change in the intensity of the light falling on the cell immediately produces a corresponding change in the resulting electric current. By means of properly designed amplifiers, it is possible to intensify this rather feeble electric current to any desired amount, and so the following applications among hundreds of others are practicable: automatic counting of objects when these objects are made to interrupt a beam of light, turning on of artificial light when daylight falls below a certain level, talking movies, television. However, it is not within the scope of this article to discuss the methods whereby these applications are realized; such a discussion now has become the province of the electrical engineer rather than that of the physicist. The purpose of this article is to give an account of the fundamental laws of photoelectric phenomena and their significance in the theory of the nature of radiation and of matter.

In studying the photoelectric effect, the principal characteristics of the radiation will be considered on the one hand, and those of electric current on the other. The chief variables involved in the radiation so far as the photoelectric effect is concerned are its intensity, its wave length, and its state of polarization. The photoelectric current has been shown to consist of a flow of electrons from the illuminated surface (restricting the discussion for the present to the photoelectric effect most investigated—that prevailing at metal surfaces). These photoelectrons vary in number, in velocity, and in direction of emission from the illuminated surface; it is the problem of the experimental physicist to find how these variables depend on the radiation variables, enumerated previously. Then again, different materials have different photoelectric effects, and therefore systematic studies of the photoelectric behavior of different materials have been carried out.

The photoelectric effect is of considerable significance in that it furnishes evidence as to the nature of radiation. The nineteenth century was a century of triumph for the wave theory of light. All the accumulated experimental evidence pointed in one and the same direction, namely, that light could be described completely as a wave motion in the hypothetical ether. These waves are essentially continuous in space and time. That is to say, the amplitude, if it changes, changes smoothly in any direction, and, if any one spot be considered, at that spot it changes continuously with time. At the end of the century, Planck found it necessary to introduce an element of discontinuity into radiation to account for the characteristic shape of the curve for the distribution of energy in the spectrum of an ideal black body. Following this notion of discontinuity in radiation and deciding to abandon altogether all elements of continuity in radiation in order to account for the photoelectric effect, Einstein in 1905 proposed to regard radiation as being made up of a torrent of tiny particles—corpuscles, photons, or quanta. Since then, a multitude of phenomena have been found which fit in most naturally with the new way of regarding radiation.

Optical phenomena fall into 2 classes: One great class includes all phenomena that can be interpreted only by the wave theory; the other contains a vast quantity of experimental results accumulated since 1900, which can be accounted for only by the corpuscular or quantum theory. To use the words of Sir W. H. Bragg, physicists at one time were content as a temporary expedient "to work with one theory on Mondays, Wednesdays, and Fridays, and with the other theory on Tuesdays, Thursdays, and Saturdays, but with the expectation that later on something could be done about reconciling the two totally different viewpoints." Recently it has been found that the ultimate particles of which matter is built, that is to say, molecules, atoms, electrons, protons, etc., have some properties that are describable only in terms of waves. Consequently, the present situation is such that *all* ultimate entities, radiation as well as atoms and electrons, have this twofold aspect: they seem to be particles and not waves for certain phenomena, and waves and not particles for other phenomena. Unable as physicists are to "picture" how this can be so from any large scale analogy that can be seen, touched, or handled

they accept this dualism as being a necessary, but unexplainable, part of a complete description of radiation and atomic phenomena. Photoelectric evidence in support of the corpuscular aspect of radiation now will be discussed.

Number of Photoelectrons in Relation to the Intensity of the Light

During the past 40 years many investigators have examined the relation between the number of photoelectrons released and the intensity of the light used. The method of experimentation easily can be visualized. A photoelectric cell is connected in series with a galvanometer and with a suitable battery the voltage of which is such as to pull the photoelectrons, which are released at the surface of the illuminated cathode, away from the cathode. The intensity of the light is changed by one of several standard methods (moving the source to different distances and using the inverse square law to compute the intensity being a common method) and the corresponding photoelectric current is indicated by the galvanometer.

In principle, any photoelectric cell could be used, but several factors often prevent commercial cells from giving the true relation. In the first place, one should use a vacuum cell because in gas filled cells, where the ionization by collision in the gas magnifies the original photoelectric current, the magnification factor may not be exactly constant.

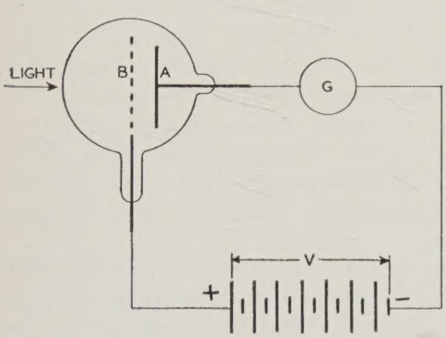


Fig. 1. Circuit illustrating fundamental properties of the photoelectric cell

Even in vacuum cells, complications often arise because the large areas of bare glass inside the cell frequently accumulate electrons which disturb the electric field inside. Also, these bare surfaces may have formed upon them monatomic transparent films of the active metal which, however, are more or less photoelectrically active and therefore contribute in an incalculable way to the measured photoelectric current from the illuminated surface.

These brief remarks may serve to explain why, in an apparatus designed to test the fundamental relations between the photoelectric current and the intensity of the light, extreme care has to be exercised to obviate any complication of the effect one is investigating. The conclusion of all investigators who have satisfied themselves that their cells are designed properly so as to measure the fundamental relationship unmodified by spurious effects, is that there is a strict proportionality between the number of photoelectrons and the intensity of the light producing them. (This relationship often is found for commercial cells, but cannot safely be assumed to be necessarily true for all such cells.) Such a result is a natural consequence of the corpuscular theory of light, for the number of photoelectrons released should be directly proportional to the number of quanta of light falling on the surface. What one should expect on the basis of the wave theory is not so clear.

Velocity of Photoelectrons and the Intensity of the Light

Velocity of photoelectrons is generally measured by, and expressed in terms of, the voltage necessary to stop them. Thus if A (Fig. 1) is the illuminated plate in front of which is a grid B, through which the light passes, the photoelectrons from A will get across to grid B, in spite of the retarding voltage V, if their kinetic energy $(^1/_2)mv^2$ exceeds Ve, the gain of potential energy, where e is the charge on the electron and m its mass. The procedure then is to increase V by small increments until the photoelectrons no longer get from A to B. When this condition prevails, the velocity of the fastest electrons is given by $Ve = (^1/_2)mv^2$.

Now it is found that the velocity of the electrons is totally independent of the intensity of the light falling on A. No matter whether the intensity of the light is so feeble that only a few photoelectrons are emitted in a minute or so strong that billions are emitted per second, the velocity with which they are emitted is precisely the same. Such an effect is quite unexpected on the basis of the wave theory of light, for, since intensity in the wave theory is measured by the amplitude of the wave, it is natural enough to suppose that the stronger the amplitude of the electric forces in the light beam, the more vigorously would the photoelectrons be ejected. Yet this is not so.

On the basis of quantum theory, the ejection of a photoelectron is, so to speak, a private affair between the electron and the quantum concerned in ejecting it. Whether few or many such quanta are raining on the surface does not matter; the velocity with which any individual electron is ejected by an individual quantum depends only on the nature of that particular quantum and is completely independent of the effects of other quanta at other parts of the surface.

Velocity of Photoelectrons and the Color of the Light

By substituting the quantum viewpoint of radiation for the wave aspect in an attempt to account for the photoelectric effect, Einstein, in 1905, made an exceedingly bold prediction as to the relationship to be expected between the velocity of electrons and the wave length of the light. According to the quantum theory, the energy in a quantum is $h\nu$, where h is Planck's constant and ν the frequency of the light. The latter depends on the wave length through the well-known relation $\nu\lambda = c$, where λ and c are the wave length and velocity of light,

respectively. Thus, the higher the frequency, or the shorter the wave length of the light, the more energy there is in the quantum. It is assumed now that when the quantum is completely and instantaneously absorbed in the surface, all its energy is taken up by an electron, which then starts off with its newly acquired energy $(1/2)mv^2$. If the quantum passes through the surface, it has to give up an amount of energy, p, to overcome surface electric forces that prevent, or tend to prevent, electrons from escaping. This leads to Einstein's famous photoelectric equation

$$(1/2)mv^2 = h\nu - p \tag{1}$$

It is clear that this equation predicts that the energy of escape is a linear function of the frequency. That this was true experimentally was established simultaneously and independently in 1912 by Hughes and by Richardson and Compton. Four years later, Millikan verified the relation to a very high degree of accuracy, so that his measurements gave a precision determination of the highly important Planck's constant, h.

The Photoelectric Threshold

It is clear from eq 1 that if there were no forces at the surface tending to hold the electrons in, then all radiation, no matter how small its frequency or how long its wave length, would eject photoelectrons with the proper energy $(1/2)mv^2$. It is the finite size of p, the "work function" of the surface, that prevents this happening. The value of p depends greatly on the nature of the material and also on the state of the surface. For example, removing occluded gases from a surface by prolonged heating may change p by a large factor, possibly often by as much as 30 per cent. A surface from which impurities, such as occluded gases, have been removed is presumably the photoelectric threshold of a "clean" metal. The alkali metals, which are electropositive (i. e., lose electrons easily), have unusually low work functions and so their thresholds lie in the visible spectrum or in the infra-red region. On the contrary, metals like platinum and tungsten, which are electronegative (i. e., part reluctantly with electrons) and are chemically somewhat inert, have relatively large work functions; their thresholds are in the ultra-violet range.

The material with the lowest known work function, i. e., with a threshold in the infra-red region, is a composite surface consisting of a supporting surface of silver, then a very thin layer of an oxide of caesium, over which is laid a *monatomic* layer of caesium atoms. Such surfaces are employed in many modern photoelectric cells, since they are sensitive to a wide range of wave lengths, and therefore give a greater response to white light than cells having larger work functions.

Fowler's Theory of the Photoelectric Effect

Previous to 1927 it had been supposed that the electrons within a metal behaved very much like molecules of a gas in an enclosure the boundaries of which coincided with those of the metal. The higher the temperature, the greater is the kinetic energy of the molecules. However, even at 1,000 deg C the average kinetic energy of the molecules (or electrons) is about $1/10$ of an electron volt.

In 1927, Pauli proposed a very different picture of the state of the electrons in a metal. According to this picture the electrons are moving with far greater kinetic energies (of the order of 6 electron volts) than they were supposed to have by the old theory. What is more significant is that their energy is almost, but not quite, independent of the temperature, whereas by the previous theory, the energy was directly proportional to the temperature. Using this new viewpoint, Fowler found that the photoelectric threshold should appear to shift slightly with the temperature—a result not to be expected on the basis of the older theory—and moreover, predicted how the photoelectric current should depend on the temperature and on the frequency near the threshold. (To be strictly correct, a clear cut threshold exists only at absolute zero; at other temperatures electrons should be found for lower frequencies, though to be sure in rapidly diminishing number at frequencies decreasing from the threshold.) This prediction was verified quantitatively by DuBridge in a series of very skillfully designed experiments. There is convincing proof therefore that the new picture of the state of electrons in a metal fits the facts better than the theory previously held.

The Selective Photoelectric Effect

In 1894, 2 of the pioneers in the field of photoelectricity, Elster and Geitel, found a remarkable dependence in the photoelectric effect of sodium-potassium alloy on the state of polarization of the light used in their experiments. They directed a beam of light obliquely at the surface. The plane of polarization of this light could be rotated by means of a Nicol prism. When the light was polarized so that the electric force coincided with the plane of incidence, under which conditions there was a component perpendicular to the surface, the photoelectric effect was far greater than when the electric force was perpendicular to the plane of incidence and so was entirely parallel to the surface. This is precisely what would be expected on the basis of the wave theory of light, for it is reasonable to suppose that if the electric force has any component perpendicular to the surface it will be much more efficient in ejecting photoelectrons than when it is entirely parallel to the surface. An immense amount of work has been done on all kinds of surfaces in this field. For years quantitative correlation with theory was impossible to effect. It is true that when the light is polarized in the plane that gives the bigger effect, more of it is absorbed than when it is polarized in the other plane; but the trouble is that the difference is not nearly large enough to account for the large differences in the corresponding photoelectric effects.

Extensive work by Ives at the Bell Telephone Laboratories has shown that a radically different

point of view is necessary to bring theory and experiment into accord. It is well known that when waves of light are reflected in part from a surface the reflected waves combine with the incident rays to give a pattern of standing waves in the vicinity of the surface. The amplitude, and therefore the energy, of the electromagnetic disturbance may be computed just at the surface. The magnitude of this will depend greatly on the angle of incidence and on the state of polarization of the light. It is found that the magnitude of the photoelectric effect is related closely to the energy of the disturbance. Consequently, this new viewpoint of Ives may be considered to be a very important contribution to the theory of the selective effect.

Photoconductivity

So far, the effects arising when light falls on a metal surface have been considered; in addition, electrical effects are to be found when light is absorbed throughout a finite volume of some semitransparent substance. The change in resistance of a certain form of selenium when illuminated, was known long before the ordinary surface photoelectric effect was discovered. Yet, although hundreds of investigations have been made of it, but little is known as to the totality of effects in selenium. It was recognized that the photoconductivity of selenium probably was related to its crystalline structure. This led to a study of the effect of light on the conductivity of large single crystals. Practically all the present information in this field has been acquired since 1920 and has resulted almost entirely from the work of 2 Germans, Gudden and Pohl.

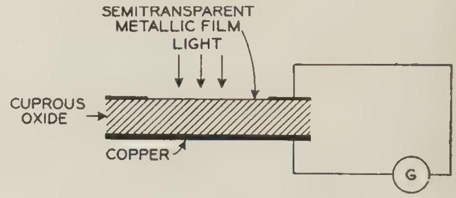
Comparatively few crystals change in conductivity when illuminated; in those that do, a secondary effect, not at all photoelectric in its nature, generally obscures the fundamental photoelectric effect. Thus any considerable photoelectric current passing through a crystal when illuminated alters it in such a way as to diminish its resistance. Hence, in order to study the underlying photoelectric effect successfully, it is necessary to work with the smallest possible currents so as to secure the least possible disturbance of the crystal. When this is done properly for crystals such as diamond and zinc blende, the photoelectric current is found to be directly proportional to the intensity of the light. It starts and stops instantly with the light. Perhaps the most convincing result found is that the number of photoelectrons released is very nearly identical with the number of quanta absorbed in the crystal. Under the influence of a sufficiently strong field the electrons released will move toward the anode, leaving the places from which they started positively charged. This results in the building up of a strong space charge within the crystal, an effect readily demonstrated.

In certain crystals, such as rock salt, no photoelectric current can be found if the crystals are perfectly clear and transparent. Such crystals sometimes can be colored by long exposure to X rays and by other agents. When in this state, they show strong photoconductivity on illumination by visible light. It is believed that the colored rock salt owes its color to the presence of neutral atoms of sodium dispersed through the regular rock salt lattice. When light is absorbed by any one of these neutral atoms, it emits a photoelectron and so the existence of a photoelectric current is accounted for.

Cuprous Oxide Cells

It has been known for a long time that, if cuprous oxide (Cu_2O) is formed on copper by heating in oxygen, the interface between the oxide and the

Fig. 2. Cuprous oxide photoelectric cell devised by Lange in 1930



metallic copper acts as a rectifier. If a current be considered as a flow of electrons, such an interface offers a high resistance to the movement of the electrons when the voltage drop is such as to drive them from the oxide to the copper; but it offers a low resistance to the movement of the electrons when the voltage drives them from the copper to the oxide. In 1926, Grondahl noticed that the behavior of such a rectifier was influenced by illumination, and realized that it could be used as a photoelectric cell. Nothing further was done until 1930 when Lange devised an arrangement of the materials to allow as much light as possible to reach the sensitive interface and so give a large photoelectric current; his arrangement is shown in Fig. 2. A thin layer of cuprous oxide is formed on a base plate of copper, which forms one electrode. The other electrode may be a grid pressed on the top surface, or a semitransparent film of metal deposited by evaporation or sputtering. When light falls on such a cell, it is found that the photoelectric current is directed so that electrons flow from the oxide to the copper—an unexpected result, for this is the direction in which the device, regarded as a rectifier, has a high resistance.

The yield of such cells is astonishingly high, a result that, because of its practical implications, led to an intensive study of such cells immediately after Lange published his discovery. It should be noted that this cell gives a photoelectric current without any need of an auxiliary battery to supply voltage. This must mean that the kinetic energy of the electrons is sufficient to carry them across the interface from the oxide to the copper. The fundamental primary effect at the interface may be either the development of an electromotive force or the development of a current. Experiments carried out by Auwers and Kirschbaum show that the latter is correct. Such a result is in accord with the view that each quantum of light sets free a photoelectron and the current is directly proportional to the num-

ber of photoelectrons made available. It is found that the passing of the photoelectrons across the interface tends to set up a voltage difference across it which, because it is in the direction of easy flow for the electrons across the boundary (regarding the cell in its rectifier aspect), causes many of the electrons to leak back across the interface. Thus the cuprous oxide cell itself tends to act as an undesirable shunt, which allows some of the photoelectrons to leak back instead of going through the indicating instrument in the outer circuit. Because of this effect it is desirable to keep the resistance of the outer circuit, including the meter, as small as possible. When this is done, the current indicated by the instrument is found to be very closely proportional to the amount of light falling on the cell.

The cuprous oxide cell has a threshold in the far infra-red region, and a maximum sensitivity in the near infra-red region, i. e., not far from the red boundary of the visible spectrum. The position of the maximum is determined, in part, by the strong absorptive properties of the oxide which, even in a thin layer, absorbs the visible spectrum strongly and so allows very little light to pass through to the interface where the photoelectric activity originates. Such a view is confirmed by the results obtained with a "front wall" cell, i. e., a cell so made that the active interface is the one between the semitransparent metal film and the copper oxide. In such a cell there is less absorbing material for the light to go through and, as would be expected, a much greater sensitivity in the visible spectrum. Further information about the photoelectric effect may be found in:

1. Photoelectric Phenomena, A. L. Hughes and L. A. DuBridge. McGraw-Hill Book Co., New York, 1932.

2. Photoelectricity, H. S. Allen. Longmans, Green and Co., New York and London, 1925.

3. Photocells, V. K. Zworykin and E. D. Wilson. John Wiley and Son, New York, 1930.

4. Cuprous Oxide Rectifier and Photoelectric Cell, L. D. Grondahl. *Review of Modern Phsyics*, v. 5, 1933, p. 141.

5. Photoconductivity, C. M. Nix. *Review of Modern Physics*, v. 4, 1932 p. 723.

Television by Electronic Methods

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A number of recent advances in television methods, such as electronic scanning, receiver synchronizing via the signal channel, and light sensitive devices of great sensitivity have made possible the construction of television equipment which is thoroughly useful. Scenes with motion thus may be transmitted instantaneously, and the resulting image is stated to be almost equal in detail to good home motion pictures. The various units of a complete modern television system are discussed in this paper, with particular emphasis on the scanning, amplifying, and light translation devices. Transmission is stated to be feasible by either wire or radio.

TELEVISION, for many years a dream of inventors, has become a reality through the ingenious application of fundamental principles in electrical engineering. It differs from other methods of electric communication, including particularly telephotography, by providing practically instantaneous transmission and reproduction of scenes with the illusion of motion. Its development has reached a stage where broadcasting and reproduction of entertaining programs are technically feasible. Pending commercialization, development proceeds toward improving details.

Several outstanding advances in television methods have made possible its present practicality. Among these are electronic scanning, receiver synchronizing via the signal channel, light sensitive devices of greater sensitivity than the simple photoelectric cell, and improved technique and apparatus for amplification. The relation between essential units of a complete modern television system incorporating these late improvements is shown diagrammatically in Fig. 1. The various units of the system will be discussed in detail following an outline of the system with reference to this diagram.

The transmitter centers about the "pick-up" or analyzer which, in the Farnsworth television system, is known as the "image dissector," *A* in Fig. 1. This vacuum tube converts the various light intensities of a scene focused upon its photo-sensitive surface into fluctuations of an electric current. It is also part of the scanning system which includes its enveloping coil assembly *B* and the scanning oscillators *C* and *D*. Their combined function is to analyze

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the area of the scene into a regular succession of space elements and convert them into corresponding signal currents suitable for transmission over a single communication channel. The current impulses are amplified by the electron multiplier E, which is an integral part of the tube, and by the vacuum tube amplifiers F and G, to produce signal voltages great enough to modulate a radio carrier. The connections H and K between the scanning circuits and the amplifier provide signal impulses for automatically synchronizing the reproducers which are tuned to the transmitter.

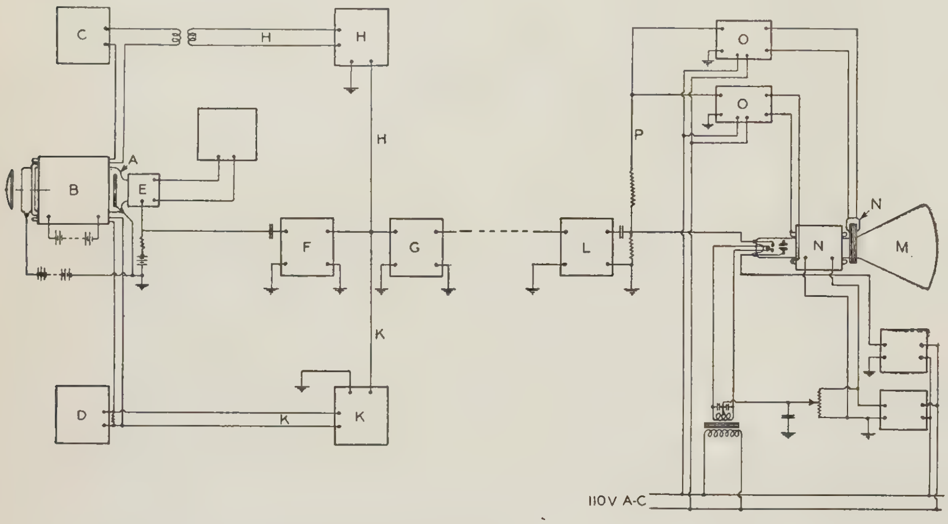


Fig. 1. A modern television system, showing elements of transmitter and receiver

The heart of the reproducer is the cathode ray tube M which converts the received electric impulses into corresponding variations of light intensity, and arranges them in regular space sequence so as to reproduce the image of the scene at the transmitter. This is accomplished with the aid of the scanning system consisting of the coils N-N, the associated oscillators O-O and the tube M itself. Again the scanning oscillators are linked to the signal channel, as indicated by P, to effect automatic control from the transmitter.

Action at both the transmitter and the reproducer involves the same general processes, namely: scanning, light translation, amplification, and the intermediate propagation of the signal. The scanning process at the transmitter analyzes the space dimensions of the field of view into a time function of electric current; that at the reproducer synthesizes the electric currents into an orderly space sequence. The light translation process at the transmitter converts light intensities into electric intensities, and at the reproducer performs the converse operation. Amplification compensates for the inefficiencies of translation and transmission while propagation of the signal completes the train of processes.

Scanning

The effect of scanning is similar to that obtained by moving a small aperture, h units in width and height, horizontally across the picture field, as indicated in Fig. 2. If the aperture is moved across n closely adjacent parallel strips, it covers an area

$$H = n \times h \text{ units high} \tag{1}$$

The 2-dimensional area of the picture is thereby reduced to 1-dimensional line. The picture is thus dissected into elementary squares each of whose different average intensities in light is converted into different intensity or magnitude of electric current. Consequently, the 2 characteristics of an electric current, its duration in time and its magnitude or amplitude, convey the space dimensions and light intensities, respectively, of a scene over a single channel as a magnitude-time function.

Conversely, at the receiver, the magnitude-time function is converted into 2-dimensional space areas of different light intensities, regularly assembled to constitute a visible duplicate of the image at the transmitter.

The signal-producing and picture reproducing mechanism cannot distinguish detail smaller than

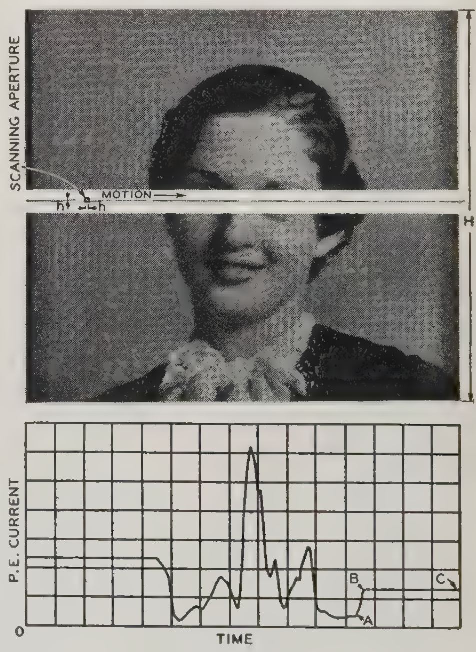


Fig. 2. The scanning operation

The aperture and scanning line are of proportions for 240-line picture

The wave below the picture results from scanning the line set apart

scanning aperture. Therefore, the amount of detail in a reproduced picture depends upon the size of the scanning aperture and upon the ability of the electric circuits to respond to the rapid changes of signal intensity during scansion. As the circuits are generally designed to respond to as many changes of intensity per unit length of scanning line as there are lines per unit height of picture field, it is customary to define the detail in terms of the number of lines in the field. Experiments indicate that at least 200 lines per picture field are essential in producing pictures that are satisfactory for sustained entertainment. (See "Television," a book, by Edgar H. Felix, McGraw-Hill Book Co.; and "Notes on Television Definition," by W. H. Wenstrom, I.R.E. *Proc.*, v. 21, no. 9, 1933, p. 1317–27.)

The time allowable for scanning the entire picture, as determined from the eye's persistence of vision, may be from $^1/_{12}$ to $^1/_{30}$ sec, depending upon the rapidity of motion of objects in the scene, the tolerable amount of flicker, and the brilliance of reproduction. (See "The Principles of Optics," a book, by A. C. Hardy and F. H. Perrin, McGraw-Hill Book Co.) Periods of $^1/_{20}$, $^1/_{24}$, and $^1/_{30}$ sec are common in current experimental work.

Electronic Scanning

Electronic scanning with the image dissector analyzer and its auxiliaries, *A-B* Fig. 1, closely approaches the elementary operation of Fig. 2. It is accomplished by periodic magnetic deflection of cathode rays set up by an optical image of the scene to be transmitted. Scanning in this device is closely associated with light translation as they both take place in the same tube.

In operation of the image dissector, Fig. 5, a lens a produces an optical image of the scene to be transmitted on the translucent photo-electric film b. This emits electrons in numbers proportional to the intensity of illumination of the optical image. Electrons from any point of the image on b are brought to a focus at a corresponding point on the anode x to which they are drawn by its positive potential. The

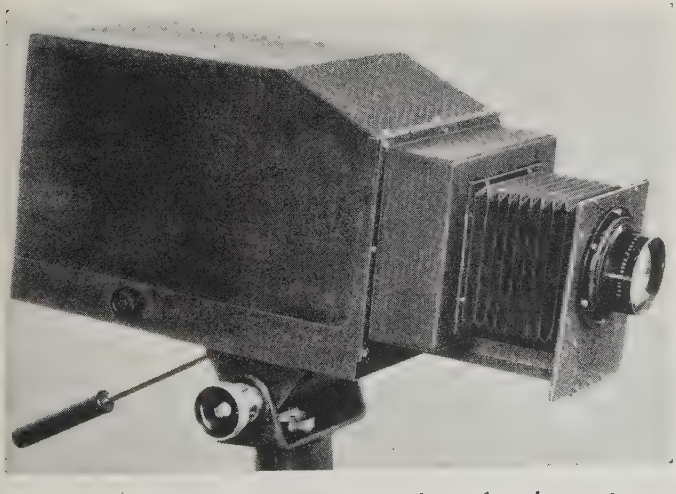


Fig. 3. Television pick-up; analyzer for electronic scanning

focusing is accomplished electromagnetically as described in Appendix I, where it is shown that the d-c field of coil c overcomes the divergence of the electron paths indicated by the dotted lines d. The result is as if the electrons all traversed parallel paths e. Thus, the distribution of cathode rays impinging upon the surface of x represents truly the optical image on b, and an electrical image is said to exist in the plane of x.

In the center of x is a square aperture i whose area is $h^2 = (H/n)^2$ from eq 1, where H is determined by the dimensions of the tube and n by its intended

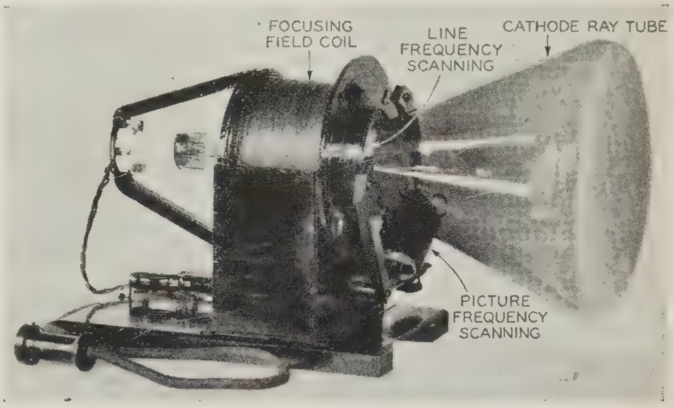


Fig. 4. Television reproducer; synthesizer for electronic scanning

application. Aperture i selects the cathode rays from an elementary area of the electrical image as the aperture in Fig. 2 selects the light. Thence the rays pass into compartment v containing the elements of an electron multiplier which is part of the amplifier. These rays constitute an electron current flowing into v, whose magnitude is always proportional to the brightness of the part of the optical image whence the electrons are emitted. This current constitutes the initial picture signal which is amplified in v, and succeeding stages F and G of Fig. 1.

To scan the scene, alternating currents are supplied to coils o and q, Fig. 5. Their transverse magnetic fields, superimposed on the longitudinal d-c field of coil c, cause the cathode rays e to bend as explained in Appendix I. This displaces the electrical image on x by an amount proportional to the instantaneous value of the scanning current. The fields of o and q act at right angles to each other. The amplitude of current in o and in q is each adjusted to cause a total displacement equal to the corresponding dimension of the image on x. The a-c supplied to coil o has a frequency equal to the picture frequency, N. The frequency supplied to coil q is N times the number of scanning lines desired. For a 240 line picture repeated 24 times per second, o would carry a 24 cycle current and q a 5,760 cycle current. The resultant horizontal and vertical motion of the electrical image across the aperture i is equivalent to a traversal of the image by the aperture as described in connection with Fig. 2. A complete analyzer unit including lens and scanning coils is shown in Fig. 3. Current for the tube and

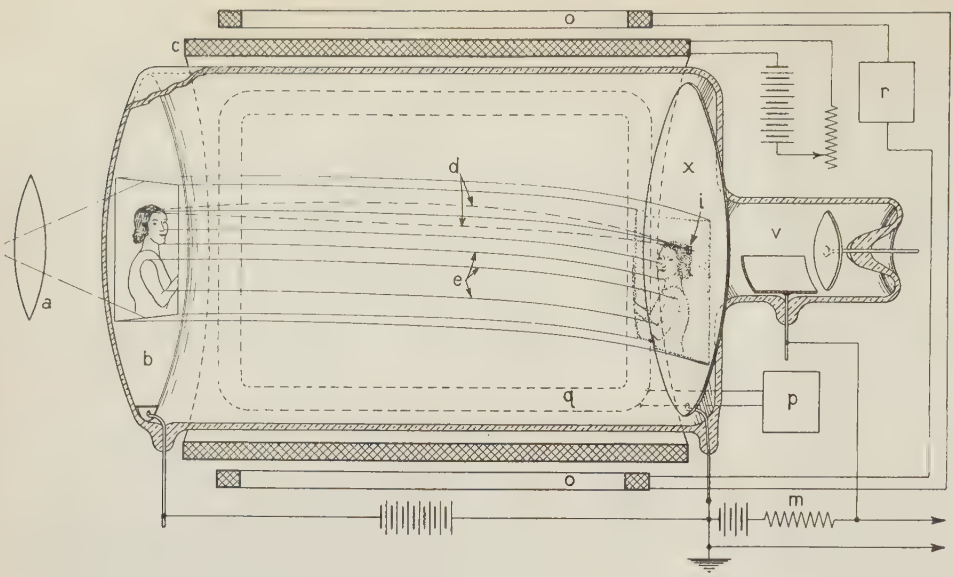


Fig. 5. The Farnsworth image dissector

scanning coils is supplied over a cable which also has a conductor for the signal output.

Sawtooth Wave Required for Scanning

The scanning currents are supplied to coils *o* and *q* by vacuum tube oscillators *r* and *p*, respectively, Fig. 5. The wave form of these currents is important because the signal intensity depends upon the rate of scanning. Therefore, if the rate of scanning is ununiform across the width of a picture field, the signal will not bear the same relation to light intensity in all parts of the field. This effect is exaggerated by the reproducer so that the picture appears to be unequally illuminated. To insure a uniform scanning rate a "sawtooth" wave form scanning current is employed. (See Fig. 7.) Such a wave form provides straight-line variations with time for scanning (*C-A* Fig. 7), and quick back-traces *A-B*. The latter provide convenient intervals in the picture signal for transmission of synchronizing impulses to control reproducer scanning. In Fig. 7 is shown the relation between the synchronizing impulses and the scanning wave.

The circuit of the oscillators used in the Farnsworth system to supply the sawtooth scanning currents is shown in Fig. 6. It employs a special tetrode similar to the ordinary power tubes employed in radio receivers except for the grid used for synchronizing. The circuit is similar to that of the conventional vacuum tube oscillators, but the peculiar wave form results from 2 unusual circuit parameters. First, the iron core transformer works in the region of saturation during part of the cycle; second, the grid of the tube is over-excited by an excessively large voltage developed in the grid winding of the transformer. The frequency is adjusted by varying the time constant of the *R-C* circuit in series with the grid winding. In the reproducer, the frequency, when set to the approximately correct value by variation of the grid leak, is controlled by signal impulses applied to the synchronizing grid of the tube. The same circuit, except for the manner of connecting to the deflecting coils, is used for both low and high frequency scanning. The generators consume from 10 to 30 watts each and are entirely dependable. The same type of generator is used in transmitter and receiver.

Electronic Scanning in the Reproducer

Electronic scanning in the reproducer operates on essentially the same principles as it does in the analyzer. The chief difference is that the electron stream in the cathode ray reproducer tube is of small cross section in contrast to the complex bundle of rays in the image dissector. The small ray in the reproducer tube is magnetically focused to a small spot on the fluorescent screen in the tube and is deflected back and forth across the screen by fields

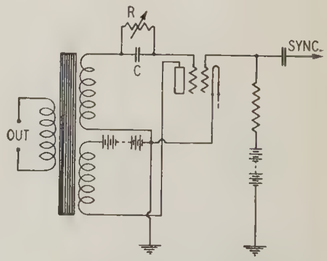


Fig. 6. A sawtooth wave generator

of sawtooth alternating currents in such a way that the desired area of the reproduction is traced with 240 or more parallel lines each $^{1}/_{24}$ sec. The picture signal acting on a grid in the cathode ray tube modulates the ray as it moves about and thereby reproduces the scene upon the fluorescent screen.

Light Translation in the Analyzer

Light translation in the photo-electric film of the analyzer is essentially a conversion of light energy into that of electron motion whereby electrons are released from the photo-surface. The chief requirements of the photo-electric film for television are sensitivity, rapidity of response, electron emission,

linearity between emission current and light intensity, and response to a convenient color range.

Maximum sensitivity and rapidity of response are made particularly necessary by the scanning operation as shown by the following example. It was determined by experiment with the dissector that a picture field illuminated at an intensity of 188 ft-c produced an image of 1.37 ft-c intensity on the surface of *b*, Fig. 5, when a fast lens was used. The area of the image on *b* was 0.0875 sq ft and the photo-electric sensitivity 35 μa per lumen. The total emission was 4.2×10^{-6} amp. The emission from an element of area, the size of the scanning aperture, for 240-line scanning would be $4.2 \times 10^{-6}/n^2 = 0.695 \times 10^{-10}$ amp. In Appendix II it is shown that an aperture of this size crosses a boundary in 0.725 μsec. Thus the quantity of electricity would be $0.725 \times 10^{-6} \times 0.695 \times 10^{-10} = 0.504 \times 10^{-16}$ coulomb or only 317 electrons.

In television transmission from motion picture film a much more intense illumination is possible than that assumed in the foregoing example. This makes limited sensitivity a less serious difficulty in motion picture transmission. By use of the electron multiplier, small electron currents such as those of the above example are readily amplified so that scenes from life with very moderate light intensity may be transmitted.

The alkali metal film photo-electric surfaces are electron emissive and their light response is very nearly linear. For this reason they qualify for television use. Sunlight and the light from incandescent lamps is rich in red radiation and for this reason a red sensitive photo-electric material is to be preferred. A film formed of caesium on oxidized silver is by far the most sensitive of all materials to red light and at the same time it meets the other requirements named above. It is therefore used in the image dissector. Caesium-oxide-silver films have a sensitivity to light from the mazda lamp, ranging from 20 to 40 μa per lumen. This sensitivity is 10 times as great as that of a plain metallic caesium surface and about 10,000 times as great as that of a metallic potassium surface.

Light Translation in the Reproducer

In reproduction of light from the television signal the character of light source is much influenced by the method of scanning. The sources of artificial light are relatively few, namely: incandescence, ionization of gas, and fluorescence (or phosphorescence). Incandescence of the familiar types and gas ionization are too sluggish to operate well with the high scanning speeds now in use and they are not well adapted to electronic scanning. Fluorescence has the advantage of responding to an excitation of very short duration as well as making the direct application of cathode ray scanning relatively simple. There are a large number of fluorescent materials, but the one favored at present for use in tubes for television purposes is synthetic zinc silicate closely resembling in composition the mineral, Willemite. Two outstanding qualities effect its choice: It is highly resistant to chemical decomposition under electron bombardment, and the pale green light which it produces is near the color range to which the human eye responds most strongly. The intensity of illumination is approximately proportional to the current in the cathode ray, which makes possible an illumination response nearly linear with respect to signal voltage in a properly designed tube. A strong cathode ray will produce a fluorescent light intensity of several candle power, which is adequate for a small field.

Excellent pictures can now be reproduced for viewing directly on the cathode ray tube; these may be as large as 5 by 7 in. A tube for this service is shown in Fig. 4. They are bright enough to be viewed in a moderately illuminated room, and are almost equal in detail to good home motion pictures. Much attention is now being given to development of tubes which will produce pictures of sufficient brilliance to permit projection, while retaining the outstanding good television characteristics of the present tubes.

Amplification

The unusual wave forms typical of television, and the exceeding smallness of the current output from a picture element, combine to make severe demands

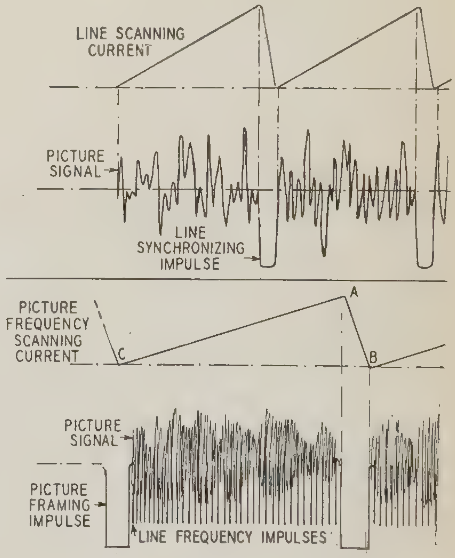


Fig. 7. Sawtooth scanning waves, television signal, and synchronizing impulses showing relative positions on time axis

upon an amplifier if it is to give true reproduction. The resistance-capacitance coupled amplifier is employed at the transmitter (*F* and *G* Fig. 1) and the receiver. Being designed for a wide band of frequencies and good transient response, it meets the requirements in all respects except amplification of the minute initial signals produced by low levels of light intensity. The capabilities of the amplifier are shown by analysis of a typical signal, Fig. 2, which it transmits. This wave was obtained by plotting photo-cell currents due to light passing through an aperture moved across the picture as indicated.

The outstanding characteristics of the wave in Fig. 2 which determine the requirements of the am-

plifier are: Amplitude range, transient nature of parts of the wave, range of frequency components, and dissymmetry.

The amplitude, corresponding to ranges of light intensity, expressed by the ratio of maximum to minimum photo-electric current, is found to be 30:1. The wave is made up of parts approaching

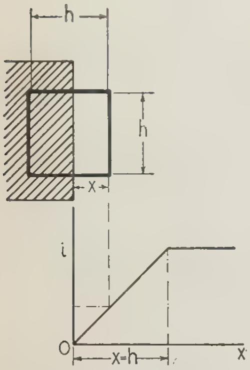
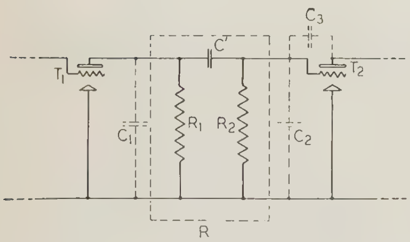
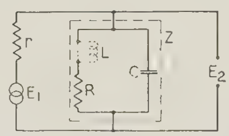


Fig. 8. Scanning across a sharp boundary

Fig. 9 (left, below). Schematic of resistance-capacitance coupled amplifier stage

Fig. 10 (right, below). Equivalent circuit of an amplifier stage





straight lines, not periodically repeated and therefore of transient nature, of which A-B is typical. A-B approaches the ideal wave produced by scanning across a sharp boundary as shown in Fig. 8. Using the symbols from this figure, the current may be expressed:

$$i = khx = khvt \tag{2}$$

where k is a constant and v is the constant velocity of the scanning aperture. This equation, from Fig. 8, explains the straight line character of the parts of the wave of Fig. 2. The highest frequencies in the picture signal are found from eq 2 as shown by Appendix II and are equal to $^1/_2Nn^2$ where N is the number of picture repetitions per second and n is the number of scanning lines per picture. This frequency is 691 kc when $N = 24$ and $n = 240$. By contrast, the lowest frequencies of the signal are generally equal to the picture frequency N.

Dissymmetry of the picture signal wave exhibited by Fig. 2 is common. The high peaks corresponding to the brilliant areas of the picture are termed the positive signal. The synchronizing impulses which are introduced at the end of each scanning line and at the end of each picture are also unsymmetrical and are given a negative polarity and large amplitude. (See Fig. 7.) These qualities permit their selection from the picture signal for control purposes by a part of the receiver amplifier L in Fig. 1. Due to the unsymmetrical character of the signal and impulses together with a 180-deg phase-shift per stage in the amplifier, a positive signal and image can be created only from alternate stages. An even number of stages is employed with the analyzer and reproducer here described.

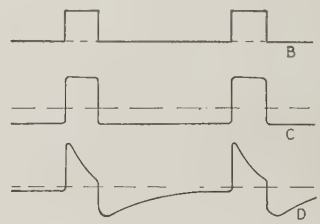
Circuit Characteristics of the Amplifier

The circuit characteristics of a resistance-capacitance coupled amplifier which are employed to provide the foregoing qualities are shown by a brief analysis of a typical stage. A complete interpretation of the transient behavior in terms of circuit constants involves somewhat difficult mathematics, but a good approximation may be had from an analysis of steady state behavior at the upper and lower limits of the frequency range.

To amplify the lowest frequencies in a typical stage such as that of Fig. 9 the resistance of R_2 is made large compared to the reactance of C'. For $f = 24$ cycles per second and $C' = 0.1$ μf, $X_c = 66{,}000$ ohms. By employing 500,000 ohms for R_2, a small number of stages gives good results. Failure to provide a large enough value for the time constant $C'R_2$ produces the distorted form shown as D in Fig. 11 from a very low frequency square-topped wave like B of Fig. 11.

At the high frequency end of the band the reactance of C' becomes neglible and the combination $R_1C'R_2$ acts as a single resistor R. But the reactance of inter-electrode capacitance in the tubes and the stray capacitance of the circuit elements to ground becomes comparable to R, thus introducing phase shift and attenuation of high frequencies. Since the highest frequencies are components of transient waves, their attenuation causes blurred and indistinct outlines or boundaries of objects in a scene, as indicated by the rounded corners of C in Fig. 11.

Fig. 11. Traces from oscillograms showing distortion of typical square television wave by a deficient amplifier



The manner in which these distortions are avoided may be shown by a brief analysis of the equivalent circuit of a single tube and its coupling unit in Fig. 10. This is a circuit of a generator with a high resistance, but is complicated by the fact that the frequency is variable between wide limits. The internal plate resistance of the tube is represented by r. Z is the load or coupling unit in which is included the sum of the inter-electrode and stray capacitances, C. Its simplest form is R and C in parallel, but it is sometimes desirable to add inductance L in the R branch so as to maintain the value of Z and limit the phase angle to a higher frequency range. E_1 is the voltage developed in the plate circuit of the tube and is equal to the product of the grid voltage and the amplification factor of the tube. E_2 is the voltage applied to the grid of the next tube.

From Kirchhoff's laws, $E_2/E_1 = Z/(r + Z)$, an expression whose values may readily be calculated by aid of the chart shown in Fig. 12. Here the horizontal lines represent resistances and the oblique lines represent reactances, those sloping to the right being capacitive and those sloping to the left being inductive. For example, line 2 is $R = 10{,}000$ ohms; line 8 gives the reactance of a 40-$\mu\mu$f condenser at various frequencies, and line 7 the reactance of a 4-mh inductance. By calculating a few values of Z for various reactances, the balance of the curve may be sketched in, and thence the values E_2/E_1 may be calculated at salient points.

Curve 3 gives Z for a typical amplifier stage with a total shunt capacitance of 40 $\mu\mu$f and indicates the effect of the falling reactance of the capacitive component. Curve 5 gives the phase angle, which reaches 45 deg at 400 kc and would cause much trouble in a picture having frequency components of this value. Curve 4 shows Z with 4 mh inductance in the R branch of the same amplifier and illustrates the improvement in the upper frequency range, the impedance holding up to 600 or 700 kc; below 400 kc the phase angle is less than in the case without inductance.

Circuit characteristics of this nature, employed with present types of radio receiver tubes, permit voltage gains of from 6 to 18 db per stage. The frequency response may be judged from the characteristics in Fig. 12. The total gain required is, of course, dependent upon the power of the radio carrier to be modulated.

The smallest value of initial signal which can be amplified by even the best amplifier is limited by spurious noise (see "A Study of Noise in Vacuum Tubes and Attached Circuits," by F. B. Llewellyn, I.R.E. *Proc.*, v. 18, no. 2, 1930, p. 243–65), associated with the input and first stage. The initial signal may easily be below this limit with the best present-day photo-electric surfaces when the light intensity is much below the value given as an example in the foregoing discussion of light translation. To overcome this limitation, an electron multiplier is employed in the Farnsworth system for pre-amplification, and a resistance-capacitance coupled amplifier used only for final stages in the transmitter.

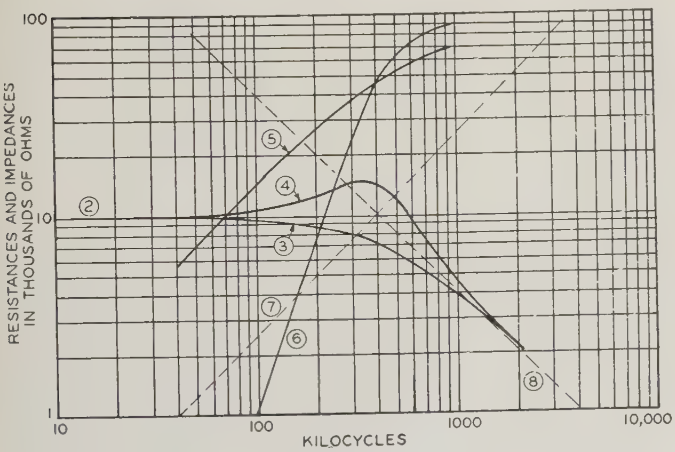


Fig. 12. Amplifier response curves

The electron multiplier E, Fig. 1, and V, Fig. 5, is an ingenious device for increasing electron currents by secondary emission. It is able to produce large amplification without distortion and makes possible the "pick-up" of television images from life with fine scanning and moderate illumination. A description of this instrument is beyond the scope of this paper.

PROPAGATION

Transmission of the television signal may be accomplished by wire or radio. Wire transmission is expensive because of the very wide frequency channels required for transmission of scenes which will sustain human interest. For this reason broadcasting by radio is generally accepted as the most useful application of television. Television seems destined to make use of the ultra-high radio frequencies in the region between 30 and 300 megacycles (10 to 1-m wave length). (See "Seventh Annual Report of the Federal Radio Commission," for the fiscal year 1933.) The propagation of these frequencies is limited to relatively short range by rapid attenuation of waves beyond the horizon, but in spite of this they offer an effective means of local broadcasting well adapted to the wide frequency channels of television.

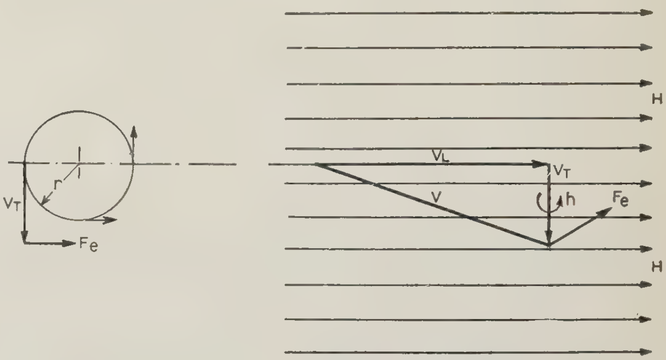


Fig. 13. Motion of electron in magnetic field

The engineering features of radio transmitting and receiving equipment for television present little that is novel, wherefore it is unnecessary to dwell on this phase of the television system.

Appendix I

Magnetic focusing of an electron stream in vacuum is based upon the fact that an electron in motion constitutes a current which is surrounded by a magnetic field (h in Fig. 13) in the same manner as a current in a conductor. (See "A Text Book of Physics," a book, by A. Wilmer Duff. P. Blakistons' Sons and Co.) Likewise it is subject to the same type of forces due to an external field. The velocity V of an electron in a magnetic field of intensity, H may be resolved into components V_L parallel to the field and V_T at right angles. (See Fig. 13.) V_T may be considered independently of V_L (see "Principles of Electricity," a book, by L. Page and N. I. Adams. D. Van Nostrand Co.). F_e represents the force on the electron due to interaction between h and H. It is always per-

pendicular to both V_T and H and its magnitude is $F_e = HeV_T$, where e is the charge on the electron. V_L has no effect upon F_e.

F_e acts as a centripetal force and the path of the electron is a circle. By Newton's law, a centripetal force, $F_c = mV^2/r$ where m = electron mass, $V = V_T$ of the preceding equation, and r = radius of circular path. Combining these equations, $H(e/m) = V_T/r$. V_T/r is the angular velocity w and e/m is constant. Therefore, if H is constant, w is constant; whence it follows that if V_T increases r decreases and *vice versa*.

A group of electrons with different values of V_T, issuing from the same point, will go around circles of different radii, r, all completing the cycles in the same time $t = 1/w = (2\pi r)/V_T$. If all have the same value of V_L, which condition can be closely approached in practice, they will travel the same distance l, in the direction of V_L in the time t, thus:

$$l = tV_L = (2\pi r V_L)/V_T = (2\pi m V_L)/He$$

Thus at a distance l from their source, all electrons of such a group occupy the same positions with respect to one another as they did at their source. If the virtual source is an aperture, as is the case of the anode of a cathode ray tube, at distance l from this aperture the electron paths converge to a bundle slightly smaller than the aperture from which they issued. Similarly if the source be a plane area such as the photo surface of the image dissector, in a plane section at a distance l the electrons come into the same relation to one another as they had at the source, and an electrical image is formed.

When a transverse deflecting field is superimposed upon a focusing field, V_L of the foregoing equations becomes the transverse velocity with respect to the new field. Then the axes of the electron rays are bent on arcs of circles by this new field until the electrons pass beyond the influence of this field. This accomplishes the deflection of the electron paths.

Appendix II

In Fig. 8, when the scanning aperture completes the crossing of the boundary, $x = h$. If the corresponding value of t is called t', eq 2 of text becomes $t' = h/v$. For a picture period of P sec and n scanning lines, $v = n^2h/P$ whence $t' = P/n^2$. When $P = {}^1/_{24}$ sec and n = 240 lines, t' = 0.725 μsec. An amplification system is ordinarily assumed to be satisfactory if it will transmit frequencies of which the period is twice that of t', that is, $^1/_2$ cycle occurs in time t'. On this basis it is usually stated for a square picture that the highest frequency in the television signal is $f = {}^1/_2 n^2/P$. Where $1/P = N$ = picture repetitions per second, $f = {}^1/_2 Nn^2$. A more rigorous equation may be provided by introducing the ratio, r, of width to height of picture, and the factor C, where the edge shadow is Ch instead of h units wide. Then $f = {}^1/_2 CrNn^2$.

Simplified Measurements of Sound Absorption

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A modification of the tube or reflected wave method for measuring the sound absorption coefficients of acoustic and building materials over a wide frequency range is described in this paper. Modern communication equipment is used, and a high degree of reliability is obtained. The method is especially well adapted to rapid routine tests of acoustic materials in commercial production, and in other instances where measurements by the more elaborate and expensive reverberation-chamber method are not justified.

THE AMOUNT of sound absorbing material in a studio or auditorium is a very important factor in determining the acoustical characteristics, and hence the suitability of such rooms for speech and music. The sound-absorption coefficients of the materials used in the construction and acoustical treatment of such rooms, therefore, must be known. The reverberation-chamber method and the tube or reflected-wave method have both been used to measure absorption coefficients. Of these, the first is usually considered the more reliable, and is the method generally accepted as standard. (For descriptions of both of these methods see "Architectural Acoustics," a book, by Vern O. Knudsen, published by John Wiley and Sons, New York, N. Y.)

An examination of the literature describing the tube methods discloses the fact that in certain of the tests, especially those made some years ago, the equipment used was unsatisfactory compared with our present high-quality microphones, loudspeakers, and thermionic-tube amplifiers. This is, no doubt, one of the important reasons the tube method was not found entirely satisfactory and has not been widely accepted.

This paper describes the results of an investigation in which modern equipment was used to determine the sound-absorbing properties of materials by a tube method. The results are very satisfactory, indicating that with inexpensive and easily obtainable apparatus it is possible to build equipment for quickly and reliably determining the sound-absorption coefficients of unknown specimens by comparing them with known materials previously standardized by the reverberation-chamber method.

Full text of a paper recommended for publication by the A.I.E.E. committee on instruments and measurements, and scheduled for discussion at the A.I.E.E. Pacific Coast convention, Sept. 3–7, 1934. Manuscript submitted May 14, 1934; released for publication June 12, 1934. *Not published in pamphlet form.*

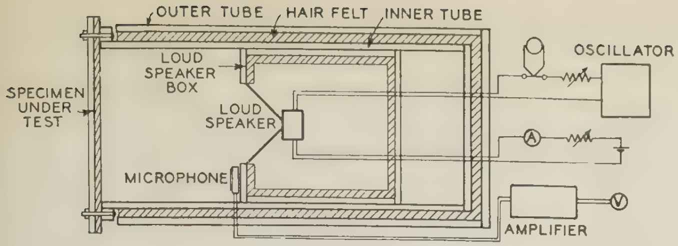


Fig. 1. Simplified diagram of apparatus used

Theoretical Considerations

When a sound wave strikes a smooth surface such as varnished wood, 3 phenomena occur. First, a very small part of the sound energy is transmitted through the wood. Second, a small amount is absorbed in air-friction losses in the surface irregularities and interstices. Third, about 97 per cent of the sound energy is reflected back into the room, causing a prolonging of the sound and, under certain conditions, excessive reverberation.

If one end of a tube is closed with some material such as varnished wood, and if a pure tone is introduced at the other end, reflection from the closed end of the tube will be almost perfect. Under the proper conditions of frequency and length of tube, standing waves with pronounced nodes and antinodes will result along the tube. These are caused by the combinations of the initial and reflected waves at various points along the tube.

If now the end is closed with a sound-absorbing material such as hair felt, only about 40 per cent (depending largely upon the type and the frequency) of the sound is reflected, and the remainder is absorbed in the interstices of the hair felt. With such a material closing the end of the tube, the reflected wave will be relatively weak and the standing waves along the tube will not be so pronounced. The sound-absorption coefficient of any specimen therefore can be determined by comparing the standing waves this unknown material causes with those produced by a previously standardized material having known coefficients.

In this investigation, simplicity, commercial practicability, and engineering reliability were considered of primary importance. Thus, although it is possible to calculate the sound-absorption coefficients from measurements made by the tube method (see previously mentioned book by Vern O. Knudsen), it was decided best to obtain these coefficients by comparison with materials previously tested by the reverberation-chamber method.

Apparatus Used

A schematic diagram of the equipment used in this investigation is shown in Fig. 1, and a front view with the test specimen removed is shown in Fig. 2. The inner and outer tubes are made of fir lumber about $^3/_4$ in. thick. The 2 tubes are separated by hair felt one inch thick. This construction keeps room noises from affecting the microphone and also largely prevents sound radiation into the room. The inner tube is provided with a wooden flange and bolts upon which the test specimen is clamped.

The loud-speaker box is made of fir plywood and is lined with hair felt one inch thick. Two hair felt baffles are also placed lengthwise in the box. This absorbing material prevents the box and the tube from exerting an appreciable influence upon the back of the loud-speaker cone.

Preliminary experiments indicated that a loud speaker having a uniform frequency response was necessary, and a moving-coil or dynamic loud speaker of the type widely used in radio receiving sets was adopted. Provisions were made, as shown in Fig. 1, for holding the input current and the field excitation at constant values.

A piezo-electric crystal microphone was used to measure the sound-wave pressure in the tube. This device is rugged, not subject to mechanical shock, has good frequency response and constant output, and is inexpensive. The microphone was connected to a 3-stage resistance-coupled amplifier using type 30 tubes. The amplifier output was measured with a copper-oxide voltmeter.

As Fig. 2 shows, the microphone was fastened directly to the loud-speaker baffle, and the entire assemblage was moved along the tube by the screw-drive arrangement shown in this figure. A coiled flexible steel tape was arranged to indicate the dis-

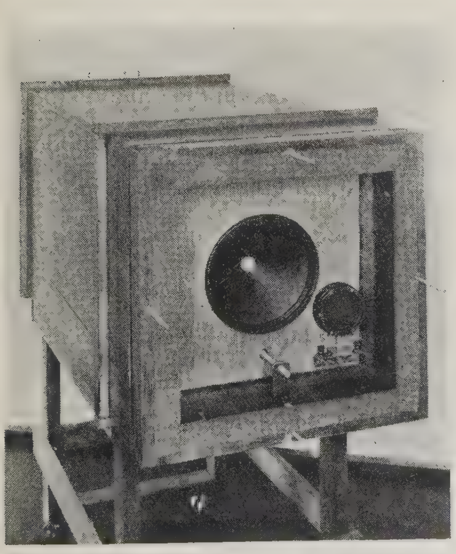


Fig. 2. Front view of equipment with test specimen removed

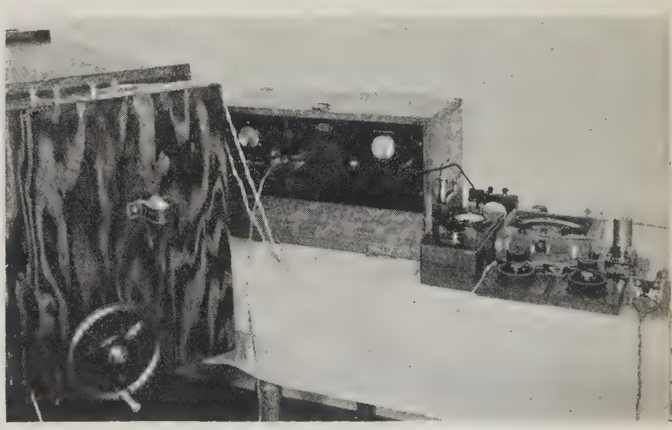


Fig. 3. Rear view of tube and of electrical equipment

tance between the loud-speaker baffle and the specimen under test. This tape, the handwheel for turning the screw, and the measuring equipment are shown in Fig. 3.

Test Procedure

After the apparatus was assembled, extensive tests were made to find the optimum loud-speaker current at the various test frequencies. Also, many positions along the tube for the loud speaker and microphone were studied to determine the best location at each test frequency.

The results of moving the apparatus along the tube and taking measurements at various points are illustrated in Fig. 4. This curve can be explained in the following simple manner. Suppose that the loud speaker and microphone are located a distance of $^1/_4$ wave length from the specimen under test, and that at a given instant the loud-speaker cone is moving forward sending out a maximum pressure wave. By the time this impulse moves forward to the specimen, is reflected, and arrives back at the baffle, the cone is moving in the opposite direction, and wave cancellation and a minimum voltage output results. Now assume that the apparatus is located $^1/_2$ wave length from the specimen under test. The path is now one wave length long, and a reflected wave arrives back at the baffle in phase with the motion of the cone, and a pressure peak results producing a maximum voltage indication.

The equipment was calibrated to measure the sound-absorption coefficients by placing materials having known coefficients on the end of the tube and observing the voltage output under the best operating conditions as previously determined. As mentioned, materials which had been tested by the reverberation-chamber method were used. From data thus obtained, calibration curves such as Fig. 5 were made for each test frequency. With these curves available, it is merely necessary to place an unknown specimen on the end of the tube, adjust the apparatus for operating conditions, measure the output voltage, and obtain the sound-absorption coefficient at the test frequency from the proper calibration curve.

Discussion of Results

As is evident, this method is simple in operation, and requires only inexpensive apparatus. The assembled equipment must, however, be carefully studied to ascertain optimum test conditions. Once the calibrations are made, they are not affected by ordinary variations in room conditions, and results can be reproduced readily. Furthermore, measurements can be made in the presence of considerable room noise, and this is a very important advantage.

In making all tests, the specimen was backed by a piece of fir plywood $^3/_4$ in. thick. This backing was found to exert some influence on the sound absorption especially at low frequency, and is possibly one of the reasons the points do not fall more closely on the calibration curve of Fig. 5. Another reason these calibration points do not fall on the curve is that wide discrepancies apparently exist in the results various observers obtain with the reverberation-chamber method. Furthermore, individual samples deviate widely from published coefficients and from the mean value of a large number of measurements (see "Less Noise—Better Hearing," v. 6, No. 1, 1934, of Celotex Acoustical Department, 919 North Michigan Avenue, Chicago, Ill.).

It may be assumed that the tube method here described is not as good as reverberation-chamber tests because in the latter, actual conditions of installation are more nearly reproduced. There is, undoubtedly, some truth in this, especially where the material is mounted on large panels which themselves absorb sound. The standardized materials used to calibrate the tube were tested, however, by different authorities under different conditions of mounting, and the agreement as Fig. 5 indicates is fairly good.

One of the important advantages of this tube method is that with a single group of equipment, tests can be made over a wide frequency range. In this investigation the coefficients at frequencies of 512, 1,024, 2,048, and 4,096 cycles were obtained readily. For frequencies below 512 cycles, the tube vibrated so badly that tests were impossible. This could be remedied by constructing a tube of thicker lumber.

Conclusions

It is apparent that the tube method of measuring the sound-absorption coefficients of various acoustic and building materials is satisfactory when modern apparatus is used. With properly calibrated equipment, the method is entirely satisfactory for original measurements over a wide frequency range. It is especially well adapted, however, for making routine tests such as required in the commercial production of absorbing materials, and for approximate determinations, where the more elaborate and expensive reverberation-chamber tests are not justified.

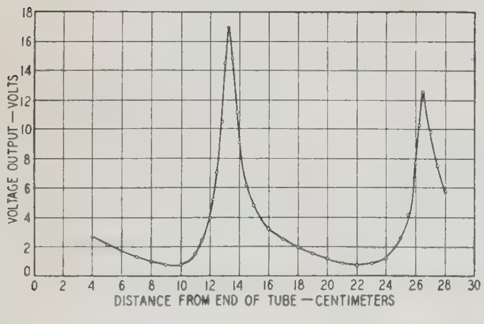
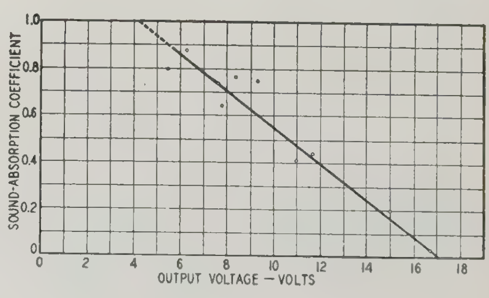


Fig. 4 (left). Voltage output of amplifier as the loud speaker and microphone are moved along the tube when it is closed with varnished wood

Fig. 5 (right). Calibration curve for tube at 2,048 cycles per second



Theory and Tests of the Counterpoise

Different theories have been advanced as to the behavior of the counterpoise in the protection of power transmission lines against lightning. In an attempt to learn more about the counterpoise and to check the theories of its behavior, a series of basic field tests was conducted. The results of these tests, made on both the parallel insulated counterpoise and the buried counterpoise, are reported in this paper. The data obtained are analyzed, and conclusions are drawn.

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THE counterpoise, consisting of conductors connected to transmission line towers so as to reduce the tower footing impedance, has recently been subjected to considerable study as a means of securing protection against lightning. The purpose of the field tests described herein was to study the action of a counterpoise in detail; particularly in the light of an analytic theory (see "The Counterpoise," by L. V. Bewley, *G.E. Rev.*, 1934, v. 37, p. 73–81) and with the object of testing the validity of that theory. Theoretical considerations had pointed to 3 major effects present in the behavior of a counterpoise:

1. The transient impedance, beginning with the initial or surge impedance effect and ending with the final or leakage resistance effect, the time of transition depending upon the ground resistivity and, due to the formation of corona, on the surge voltage.

2. The coupling effect with overhead conductors, depending primarily upon the location of the current images and the direction of the counterpoise.

3. The multi-velocity wave components, particularly the low velocity component predominating on the counterpoise and governing the time of arrival of reflections.

Various investigators have proposed different theories to account for counterpoise behavior, but there has been lack of agreement both with respect to the mechanism of the phenomena and with respect to the magnitude of the several factors involved. And this has led, quite naturally, to very pronounced differences in the calculated effects. Previous field tests on counterpoises have not been sufficiently complete in one respect or another to permit a rational verification of any theory; although these previous tests have provided several salient datum points for checking purposes. It was therefore deemed desirable to make a set of basic field tests on counterpoises which would place the analytic theory on trial and determine its exactness and rigor. The most favorable location for such tests would be in a region of very high soil resistivity and where the water level is at great depth; for under such conditions the counterpoise action is very definite. The only objection is the difficulty of securing a low resistance ground for the cathode ray oscillograph. Obviously, if the ground resistivity is nil, no effect can be expected of a counterpoise buried in earth which is already an excellent conductor. Unfortunately the circumstances under which the present tests were made were far from ideal for the purpose of studying counterpoise action, because the water level was not far down and the soil resistivity not high. Therefore the recorded effects were not as pronounced or consistent as could be desired, but nevertheless serve to verify the validity of the theory.

A lightning stroke of surge impedance Z and voltage wave E striking a transmission line tower having a ground wire, line wire, counterpoise, and footing resistance, is shown in Fig. 1. In order to simulate this condition, the test set-up was arranged as shown in Fig. 2. The portable impulse generator, representing the cloud, was 3,077 ft away from the counterpoise pole. It was rated 0.0125 μf and 1,000 kv on open circuit. The surge was initiated from the cathode-ray oscillograph over a spare line conductor.

The 3,077 ft of line between the impulse generator and the counterpoise pole, representing the surge impedance of the lightning stroke, was No. 6 copper wire supported on 30-ft wood poles with 6-unit insulators.

The portable cathode-ray oscillograph was situated at the counterpoise pole, Fig. 3, and in telephone communication with the impulse generator. Incidentally, both these pieces of equipment were veterans of several years previous field tests carried on by the lightning arrester engineering department of the General Electric Co. An independent driven ground of 60 ohms was obtained for the oscillograph about 20 ft from the pole.

At the counterpoise pole there were 2 overhead No. 6 copper wires at 8.5-ft horizontal spacing and sup-

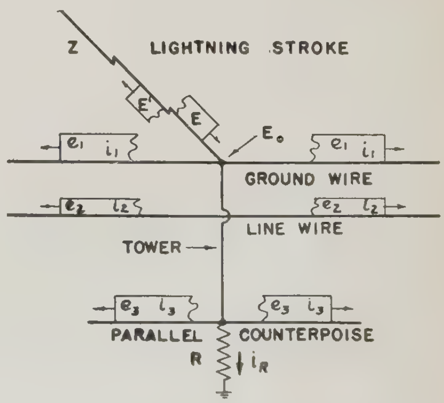

Fig. 1. Conditions at the stricken tower

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ported with pedestal insulators on 30-ft wood poles. One of these conductors could be used to represent a ground wire and the other the line wire. This was preferable to a permanent ground wire, because it allowed the ground wire effect to be segregated.

The counterpoise was a 0.25-in. steel wire with a total length of 927 ft. It was initially supported on short treated wood insulating stakes so as to avoid the leakage effect, but was finally buried in the earth to a depth of 12 in. It was first tested perpendicular and then parallel to the overhead conductors. When laid perpendicular to the line it was verified that there was no coupling with the line conductors.

Tests on Parallel Insulated Counterpoise

A 925-ft counterpoise was laid parallel and directly underneath the 2 line conductors, and grounded at its far end through pipes driven into the ground. It was hoped by this procedure to obtain very definite values for the velocity of propagation and surge impedance and hence definitely locate the voltage and current images. However, the tests under this condition were somewhat disappointing in these respects; because the earth resistivity was so low that normal test errors in the determination of the velocity and surge impedance were sufficient to cause a wide variation in the values obtained.

The tests made on the parallel insulated counterpoise are shown in Fig. 4. Three conditions were investigated:

I. Counterpoise present but disconnected, and the surge applied to one of the overhead wires. This condition is similar to that of lightning striking a ground wire at midspan. For the purpose of these tests this connection allowed the effect of the ground wire to be segregated.

II. Surge applied to the counterpoise alone, with the 2 overhead wires isolated. This test segregates the effect of the counterpoise alone.

III. Surge applied jointly to an overhead wire and the counterpoise. This condition yields the combined effect of a ground wire and counterpoise, and corresponds to the practical case of lightning striking a tower having both ground wire and counterpoise.

Table I—Tests on Parallel Insulated Counterpoise

Condition	I—Fig. 4	II—Fig. 4	III—Fig. 4
e_1	47,600	3,015 (2,850)	32,400
e_2	11,520 (11,320)	3,015 (2,850)	8,725 (9,200)
e_3	2,950 (2,330)	44,400	32,400
i_1	86 (85)		60.5 (54.2)
i_3		109 (106.5)	80 (74.3)
$F_{1.2}$	0.242 (0.238)		
$F_{1.3}$	0.062 (0.049)		
$F_{3.2}$		0.068 (0.064)	
$F_{13.2}$			0.269 (0.284)

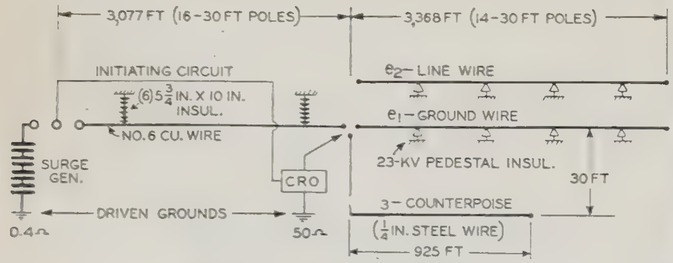


Fig. 2. Test arrangement

The average results of these tests are summarized in Table I, the figures in parentheses being calculated values, and the F's coupling factors.

The surge impedance of the counterpoise was measured in 3 different ways:

1. By the ratio of voltages at the junction between line and counterpoise.
2. By reflection from the end of the counterpoise grounded through various values of resistance.
3. By the ratio of the voltage to the current taken at the entrance to the counterpoise.

In general the 3 methods gave results of the same order, but the first method is too sensitive to small variations in the applied surges; while the second method does not take into consideration that the impulse resistance of a driven ground is somewhat lower (about 20 per cent) than its d-c resistance. Furthermore, only the last method provides a way of showing the variation of the surge impedance as function of time. From the oscillograms of condition II of Fig. 4 it is seen that after 0.5 μsec the counterpoise voltage is increasing, while its current is decreasing, so that the surge impedance is increasing with the passage of time. There was an 8.8-ohm resistance connected in series for making current measurements and therefore the surge impedance was

$$Z_3 = \frac{e_3}{i_3} - 8.8 = \begin{cases} 398 \text{ ohms at } t = 0.5\ \mu\text{sec} \\ 445 \text{ ohms at } t = 2.0\ \mu\text{sec} \end{cases}$$

The velocity determination, as ascertained by the time required for reflections to return from the end of the counterpoise, gave values from 81 per cent to 92 per cent of the velocity of light. This, of course, was the average velocity, and should be associated with the average surge impedance. The velocity on the overhead lines was between 96 per cent and 99 per cent of the velocity of light.

Fig. 3. Cathode ray oscillograph at location

Theoretically, the inductance and capacitance can be computed from the surge impedance and the velocity, and therefrom the location of the voltage and current images.

$$L = \frac{2}{10^9} \log\left(\frac{2h}{r}\right) = \frac{Z}{v} = \frac{\text{surge impedance}}{\text{velocity}}$$

$$\frac{1}{C} = 18 \times 10^{11} \log\left(\frac{2H}{r}\right) = Zv$$

in which

$2h$ = distance to current image
$2H$ = distance to voltage image
r = radius of conductor
Z = surge impedance
v = velocity of propagation

Small variations in the measured values of either Z or v will cause radical changes in the calculated value of h. Thus if $Z/v = 18 \times 10^{-9}$, then an error of only ± 5 per cent in the determination of this ratio will make a 300 per cent variation in the location of the current image. On the other hand, inductance coefficients are not sensitive to variations in h and therefore its precise determination is not mandatory. Using an average value of 420 for the surge impedance and 85 per cent for the mean velocity gives

$$L = \frac{420}{0.85 \times 3 \times 10^{10}} = \frac{16.4}{10^9} = \frac{2}{10^9} \log\left(\frac{2h}{0.125}\right)$$

$\therefore 2h = 38$ ft

$$\frac{1}{C} = 420 \times 0.85 \times 3 \times 10^{10} = 107 \times 10^{11} = 18 \times 10^{11} \log\left(\frac{2H}{0.125}\right)$$

$\therefore 2H = 4$ ft

Incidentally, these figures agree with other data, as well as theory, showing that the zero potential plane for voltage images is very close to the surface of the earth. The capacitance of the counterpoise as measured by a bridge was 3.13×10^{-9} for 925 ft as compared with 2.64×10^{-9} by the above calculation.

Using $h_3 = 19$ and $H_3 = 2$ ft, and designating the ground wire, line wire, and counterpoise by subscrips 1, 2, and 3, respectively, there are:

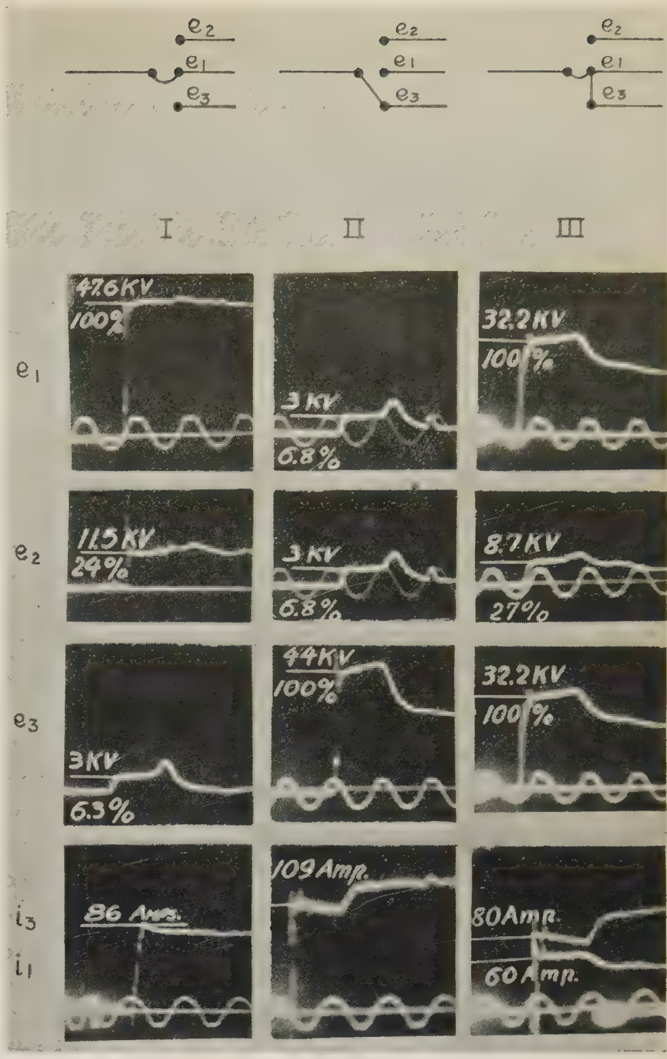


Fig. 4. Oscillograms taken on insulated counterpoise

$r_1 = 0.081$ in.	$h_1 = 48$ ft	$L_{11} = 9.55 \times (2 \times 10^{-9})$	$K_{11} = 0.1154 \div (18 \times 10^{11})$
$r_2 = 0.081$ in.	$h_2 = 48$ ft	$L_{22} = 9.55 \times (2 \times 10^{-9})$	$K_{22} = 0.1154 \div (18 \times 10^{11})$
$r_3 = 0.125$ in.	$h_3 = 19$ ft	$L_{33} = 8.20 \times (2 \times 10^{-9})$	$K_{33} = 0.1700 \div (18 \times 10^{11})$
$R_1 = 0.081$ in.	$H_1 = 31$ ft	$L_{12} = 2.43 \times (2 \times 10^{-9})$	$K_{12} = -0.0252 \div (18 \times 10^{11})$
$R_2 = 0.081$ in.	$H_2 = 31$ ft	$L_{13} = 0.84 \times (2 \times 10^{-9})$	$K_{13} = -0.0020 \div (18 \times 10^{11})$
$R_3 = 0.125$ in.	$H_3 = 2$ ft	$L_{23} = 0.84 \times (2 \times 10^{-9})$	$K_{23} = -0.0020 \div (18 \times 10^{11})$

Referring to Appendix A, the auxiliary constants are:

$I_{11} = I_{22} = 1.040$	$a_{11} = 1$	$Y_{11} = 0.1407/60$
$I_{12} = I_{21} = 0.038$	$a_{12} = 1$	$Y_{12} = 0.0892/60$
$I_{13} = I_{23} = 0.118$	$a_{13} = 1$	$Y_{13} = 0.0706/60$
$I_{31} = I_{32} = 0.059$	$a_{21} = -1$	$Y_{21} = -0.1407/60$
$I_{33} = 1.391$	$a_{22} = 1$	$Y_{22} = 0.0892/60$
$v_1 = 1.000$	$a_{23} = 1$	$Y_{23} = 0.0706/60$
$v_2 = 0.981$	$a_{31} = 0$	$Y_{31} = 0$
$v_3 = 0.836$	$a_{32} = -0.343$	$Y_{32} = -0.0612/60$
	$a_{33} = 2.965$	$Y_{33} = 0.418/60$

In terms of the multi-velocity wave components $f_1(x - v_1t)$, $f_2(x - v_2t)$, and $f_3(x - v_3t)$ the voltage surges on the 3 conductors are

$$\left.\begin{aligned} e_1 &= f_1 + f_2 + f_3 \\ e_2 &= -f_1 + f_2 + f_3 \\ e_3 &= -0.343 f_2 + 2.97 f_3 \end{aligned}\right\} \quad \text{(A)}$$

The current surges are

$$\left.\begin{aligned} i_1 &= (0.1403 f_1 + 0.0892 f_2 + 0.0706 f_3)/60 \\ i_2 &= (-0.1403 f_1 + 0.0892 f_2 + 0.0706 f_3)/60 \\ i_3 &= (-0.0612 f_2 + 0.4180 f_3)/60 \end{aligned}\right\} \quad \text{(B)}$$

The magnitudes and signs of f_1, f_2, and f_3 depend upon the terminal conditions. Corresponding to the 3 conditions of test, there are:

Condition I

$e_1 = E_0$ = voltage applied to ground wire
$i_2 = 0$ = current in line wire
$i_3 = 0$ = current in counterpoise

Hence by eqs A and B

$$f_1 = 0.381 E_0; \quad f_2 = 0.540 E_0; \quad f_3 = 0.079 E_0$$

and therefore, writing $E_0(v_1)$ for a component of magnitude E_0 traveling at a velocity v_1, there is by eq *A:*

$$\begin{aligned}
e_1 &= 0.381\,E_0(v_1) + 0.540\,E_0(v_2) + 0.079\,E_0(v_3) = (1.000\,E_0)\\
e_2 &= -0.381\,E_0(v_1) + 0.540\,E_0(v_2) + 0.079\,E_0(v_3) = (0.238\,E_0)\\
e_3 &= - 0.185\,E_0(v_2) + 0.234\,E_0(v_3) = (0.049\,E_0)
\end{aligned}$$

Due to symmetry of the overhead conductors with respect to the counterpoise, there is no v_1 component in the counterpoise surge, and the terms of this velocity balance between e_1 and e_2. The coupling factors are

$$F_{1\cdot2} = \frac{e_2}{e_1} = 0.238 \text{ and } F_{1\cdot3} = \frac{e_3}{e_1} = 0.049$$

The currents are, by eq *B:*

$$\begin{aligned}
i_1 &= [0.0536\,E_0(v_1) + 0.0482\,E_0(v_2) + 0.0056\,E_0(v_3)]/60 = (0.1074E_0/60)\\
i_2 &= [-0.0536\,E_0(v_1) + 0.0482\,E_0(v_2) + 0.0056\,E_0(v_3)]/60 = 0\\
i_3 &= [- 0.0330\,E_0(v_2) + 0.0330\,E_0(v_3)]/60 = 0
\end{aligned}$$

The surge impedance of the ground wire, therefore, is

$$Z_{11} = e_1/i_1 = 558 \text{ ohms}$$

Condition II

$i_1 = 0$ = current in ground wire
$i_2 = 0$ = current in line wire
$e_3 = E_0$ = voltage applied to counterpoise

Hence by eqs *A* and *B*

$$f_1 = 0;\ f_2 = -0.244\,E_0;\ f_3 = 0.308\,E_0$$

and therefore,

$$\begin{aligned}
e_1 &= -0.244\,E_0(v_2) + 0.308\,E_0(v_3) = (0.064\,E_0)\\
e_2 &= -0.244\,E_0(v_2) + 0.308\,E_0(v_3) = (0.064\,E_0)\\
e_3 &= +0.084\,E_0(v_2) + 0.916\,E_0(v_3) = (1.000\,E_0)
\end{aligned}$$

$$\begin{aligned}
i_1 &= [-0.0218\,E_0(v_2) + 0.0218\,E_0(v_3)]/60 = 0\\
i_2 &= [-0.0218\,E_0(v_2) + 0.0218\,E_0(v_3)]/60 = 0\\
i_3 &= [0.0149\,E_0(v_2) + 0.1289\,E_0(v_3)]/60 = 0.1438\,E_0/60
\end{aligned}$$

Thus the initial coupling factor is about 6.4 per cent, and the surge impedance of the counterpoise is

$$\frac{e_3}{i_3} = \frac{60}{0.1438} = 417 \text{ ohms}$$

By the approximate method of Appendix B, there is for comparison with the values (in parentheses) given by the complete multi-velocity theory:

$$\begin{aligned}
v_1 = v_2 &= \sqrt{p_{11}/L_{11}} = \sqrt{9.11/9.55} = 0.978\ (0.981)\\
v_3 &= \sqrt{p_{33}/L_{33}} = \sqrt{5.95/8.20} = 0.852\ (0.836)
\end{aligned}$$

$$\begin{aligned}
Z_1 = Z_2 &= \sqrt{p_{11}L_{11}} = 560\ (558)\\
Z_3 &= \sqrt{p_{33}L_{33}} = 419\ (417)
\end{aligned}$$

$$\frac{e_2}{e_3} = \frac{L_{23}}{L_{33}\,(1 + v_3/v_1)} = \frac{0.84}{8.20\,(1 + 0.852/0.978)} = 0.055\ (0.064)$$

The agreement is seen to be quite good, and thus justifies the use of the more simple approximate method.

Condition III

Referring to eqs 1 to 10 of Appendix A there results

$$f_1 = 0.358\,E_0,\ f_2 = 0.273\,E_0,\ f_3 = 0.369\,E_0$$

and the voltage and current equations are

$$\begin{aligned}
e_1 &= 0.358\,E_0(v_1) + 0.273\,E_0(v_2) + 0.369\,E_0(v_3) = (1.000\,E_0)\\
e_2 &= -0.358\,E_0(v_1) + 0.273\,E_0(v_2) + 0.369\,E_0(v_3) = (0.284\,E_0)\\
e_3 &= - 0.093\,E_0(v_2) + 1.093\,E_0(v_3) = (1.000\,E_0)
\end{aligned}$$

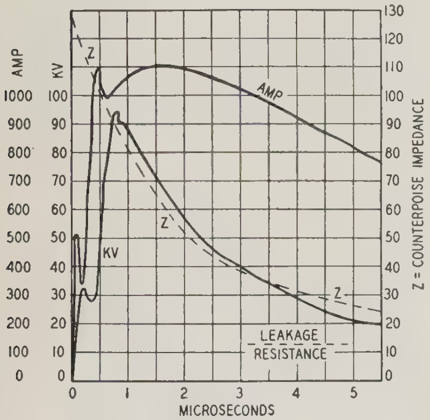
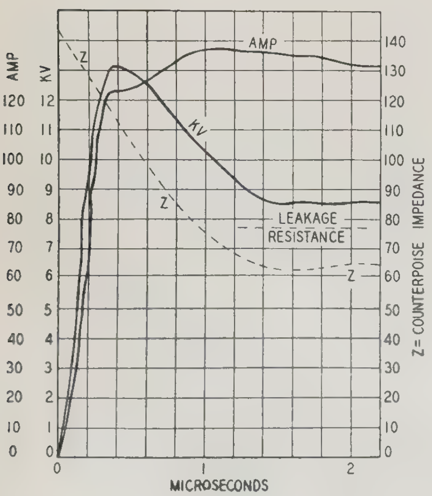


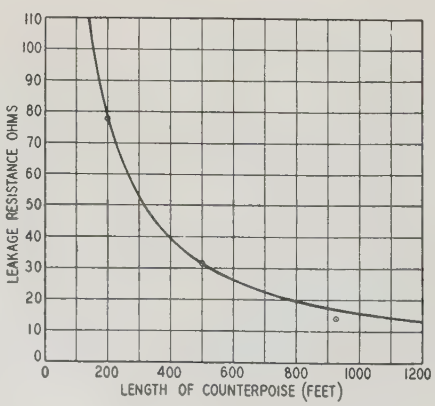
Fig. 5 (left). Transient impedance of 925-ft buried counterpoise, from oscillograms of voltage and current

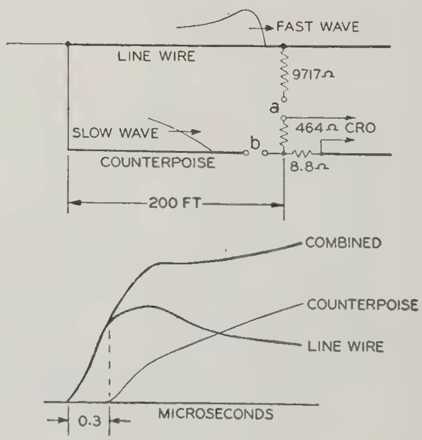
Fig. 6 (below, left). Transient impedance of 200-ft buried counterpoise, from voltage and current oscillograms

Fig. 7 (below, middle). Test points and curve of uniform leakage resistance

Fig. 8 (below, right). Method of determining velocity of propagation on the counterpoise







$$i_1 = [\ \ 0.0503\,E_0(v_1) + 0.0244\,E_0(v_2) + 0.0261\,E_0(v_3)]/60 = (0.1008\,E_0/60)$$
$$i_2 = [-0.0503\,E_0(v_1) + 0.0244\,E_0(v_2) + 0.0261\,E_0(v_3)]/60 = (0.0000\,E_0/60)$$
$$i_3 = [-\,0.0167\,E_0(v_2) + 0.1543\,E_0(v_3)]/60 = (0.1376\,E_0/60)$$

In this case the coupling is 4 per cent higher than with the counterpoise disconnected; and due to the mutual coupling between the ground wire and counterpoise the currents are less than under conditions I and II. It will be observed that when the counterpoise is connected, the surge which it carries is essentially a low velocity wave.

Tests With Buried Counterpoise

The counterpoise was buried to a depth of about 12 in., parallel and directly underneath the line conductors. Tests were made on lengths of 200, 500, and 925 ft with surges of 15 kv and 90 kv. The latter was the highest voltage at which current measurements could be made without making special arrangements to insulate the portable cathode ray oscillograph truck. For slightly higher voltages the truck tires would arcover.

In Figs. 5 and 6 are replots of voltage and current oscillograms taken on the 925- and 200-ft counterpoises, respectively, with the overhead conductors isolated. The ratio of voltage to current here is plotted as the transient impedance. Initially the counterpoise behaves as a surge impedance and finally as a distributed leakage resistance to ground. The equation for the transient impedance is given in Appendix C. The points on the plotted impedance curve lie on a smooth curve beyond 0.5 μsec, but the accuracy is very poor between 0 and 0.5 μsec. However, the extrapolation of the impedance curves on these and other plots indicates that the initial, or *surge impedance*, value lies between 120 and 160 ohms. From this value the transient impedance falls in a somewhat exponential fashion until the final, or *leakage resistance*, value is reached. In the case of the 925-ft counterpoise this final value has not yet been reached at the end of 6 μsec (at which time reflections from the generator interfered). But on the 200-ft counterpoise the transient impedance has very definitely reached its steady state value at the end of 1.5 μsec. At the instant of maximum voltage the transient impedance is 88 and 112 ohms, respectively, in Fig. 5 and Fig. 6. Very likely this impedance is considerably less at the much higher voltages corresponding to natural lightning. Incidentally, in each of 5 plots which have been made, the impedance curve closely parallels the tail of the voltage wave. The leakage resistance, Fig. 7, measured 77.5, 31.5, and 14 ohms on the 200, 500, and 925 ft lengths of counterpoise, respectively.

The propagation of a surge in a counterpoise buried in low resistive earth appears to be as much diffusion as traveling wave phenomenon. For this reason attempts to discover a velocity of propagation from reflections on the oscillograms proved futile. The abrupt change at 1.5 μsec on the tail of the voltage wave for the 200-ft counterpoise, Fig. 6, as contrasted with that of the 925-ft counterpoise, Fig. 5, was at first taken for the return of a reflection.

In order to determine more carefully the velocity, E. J. Wade devised a most ingenious method, the essential elements of which are shown in Fig. 8, the waves being replots of actual oscillograms. The surge was applied to both the line wire and the counterpoise. The cathode ray oscillograph was placed 200 ft farther along where the counterpoise was opened as shown in Fig. 8, and a series resistance of 8.8 ohms inserted. By closing a the fast wave on the line was recorded. By closing b (with a open) the flattened front slow wave on the counterpoise was recorded. Finally by closing both a and b the 2 waves superimposed after a time Δt which could be determined by placing the oscillogram of the fast wave over that of the combined wave so that their fronts coincide, and observing the point at which they diverge. It will be appreciated that the success of this method depends upon the 3 resistance elements being of widely different values, and the one to the line wire should be high. In Fig. 8 the slow wave arrived 0.3 μsec after the fast wave, and the velocity therefore is (since the fast wave travels at the velocity of light):

$$v_3 = \frac{l}{t_3} = \frac{l}{t_1 + \Delta t} = \frac{l}{\Delta t + l/v_1} = \frac{200}{0.3 + 200/985} = 400 \text{ ft}/\mu\text{sec}$$

But when this test was repeated at 500 ft the velocity was apparently only 330 ft/μsec. The reason for the decrease in velocity as the distance traveled increases is given later under "Discussion." The method of testing determines only the average velocity. Now the longer the length of counterpoise under test the less the influence of the initial higher velocity and the more nearly will the average velocity be equal to the final velocity. On the basis of this argument the velocity will be assumed as 30 per cent that of light. Taking the surge impedance as $Z_3 = 142$ and the velocity at $v_3 = 30$ per cent, the inductance and capacitance coefficients, as well as the position of the equivalent current images, are as follows:

$$L = \frac{2}{10^9}\log_\epsilon\left(\frac{2h}{r}\right) = \frac{Z_3}{v_3} = \frac{142}{0.3 \times 3 \times 10^{10}} = \frac{15.8}{10^9}\text{ h/cm}$$

$$\therefore 2h = \frac{2700}{8 \times 12} = 28 \text{ ft}$$

$$C = \frac{1}{18 \times 10^{11}\log_\epsilon (2H/r)} = \frac{1}{Z_3 v_3} = \frac{1}{142 \times 0.3 \times 3 \times 10^{10}} = \frac{0.80}{10^{12}}\text{ farad/cm}$$

$$\therefore 2H = 0.25 \text{ in.}$$

In earth of such low resistivity, burying the counterpoise may raise the effective position of the ground current considerably, because current is then flowing above and on both sides of the counterpoise as well as below it. In such cases the depths of current as determined for the insulated and buried counterpoise are not comparable. But in high resistivity soil, where counterpoises are most likely to be used, there will probably be little difference found in the location of the current image for either an insulated or buried counterpoise.

Current distribution along the counterpoise was obtained with the cathode ray oscillograph at the 0, 200, and 500-ft points. Representative oscillograms

Table II—Tests on Buried Counterpoise

Condition	Fig. 11 II	Fig. 11 III	Fig. 12 II	Fig. 12 III
e_1	1,600	14,480	5,990	90,150
e_2	1,600	4,050	5,990	23,820
e_3	16,400	14,480	94,500	90,150
i_1		40.5		187
i_3	178	161.1	1,107	1,107
$F_{3\text{-}2}$	0.098		0.063	
$F_{13\text{-}2}$		0.280		0.264

are replotted in Fig. 9. The initial current wave is quite steep, having a front of less than 0.5 μsec. There is considerable flattening of the front and drop in magnitude as the current wave travels along the counterpoise. The average values obtained from these tests at 2.5 μsec were:

Distance	0 ft	200 ft	500 ft
Current	134 amp	107.6 amp	14.4 amp

Since the counterpoise current is so rapidly drained off, the coupling effect with the overhead conductors practically vanishes within a short distance—say beyond 300 ft. Attempts also were made to measure the currents by surge crest ammeters, but the reversals due to reflections were too large to permit accurate results.

The superposition of voltage waves taken on counterpoises of 200, 500, and 925-ft length is shown in Fig. 10. There is obviously nothing to gain under these conditions by using a counterpoise longer than 200 ft for applied wave fronts less than 1.5 μsec. In soil of higher resistivity a longer length is justifiable, but it is doubtful if lengths greater than 300 ft are worth the extra cost. On the other hand, very short counterpoises of the order of 50 ft may give rise to substantial reflections which would raise the tower voltage.

In Figs. 11 and 12 are shown the effects of the buried counterpoise on coupling for the 2 conditions: (II) Surge on the counterpoise alone with the overhead conductors isolated; and (III) surge on both the counterpoise and ground wire. Figure 11 is for a low voltage surge of 15 kv and Fig. 12 is for a 90-kv surge. The data (averaged) is summarized in Table II.

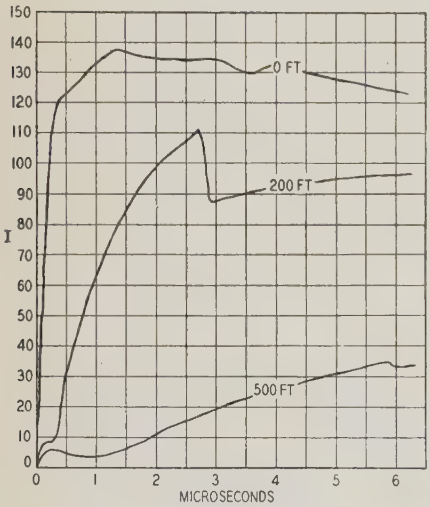
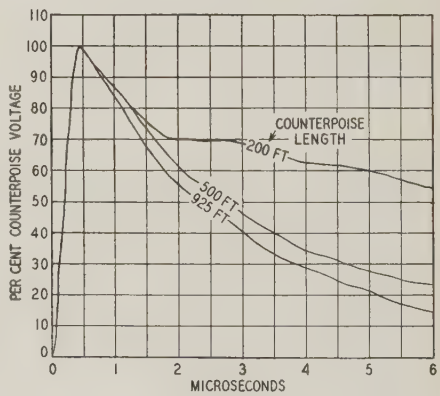


Fig. 9 (left). Current waves in 925-ft counterpoise at 0, 200, and 500-ft points

Fig. 10 (right). Superposition of voltage waves for counterpoises of different lengths



By eq 27 of Appendix B the mutual impedance between the counterpoise and the overhead conductor, based upon the current image at 28-ft depth, is

$$Z_{3\cdot2} = L_{32}\left(\frac{v_2v_3}{v_2+v_3}\right) = \frac{1.29}{10^9}\left(\frac{1 \times 0.3}{1.3}\right) 3 \times 10^{10} = 9.0$$

From Fig. 11 the current is 178 amp. Therefore, the induced voltage is

$$e_2 = Z_{3\cdot2} i_3 = 9.0 \times 178 = 1.6 \text{ kv (1.6 test)}$$

Likewise from Fig. 12 the induced voltage is

$$e_2 = 9.0 \times 1100 = 9.9 \text{ kv (6 test)}$$

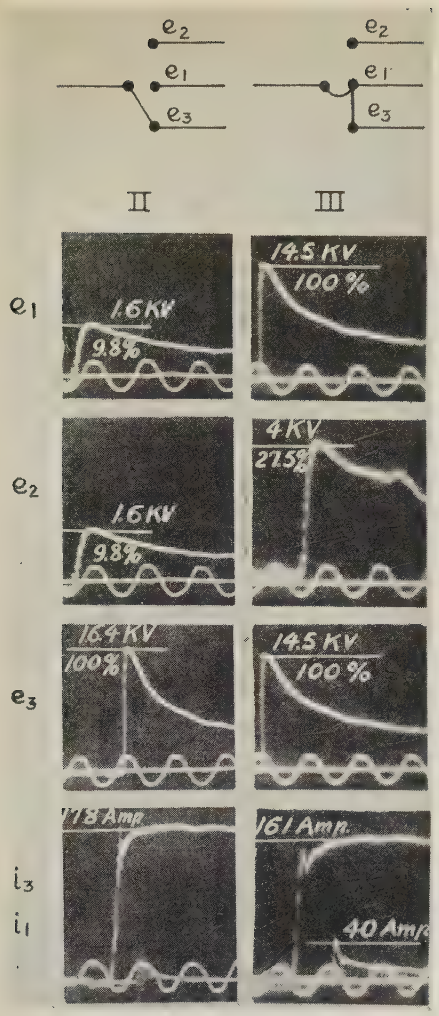
This latter is a very poor check. Presumably the only difference in the 2 tests was the higher voltage in the case of Fig. 12. But if this made any difference at all one would expect it to *increase* rather than decrease the coupling. The author has no explanation to offer.

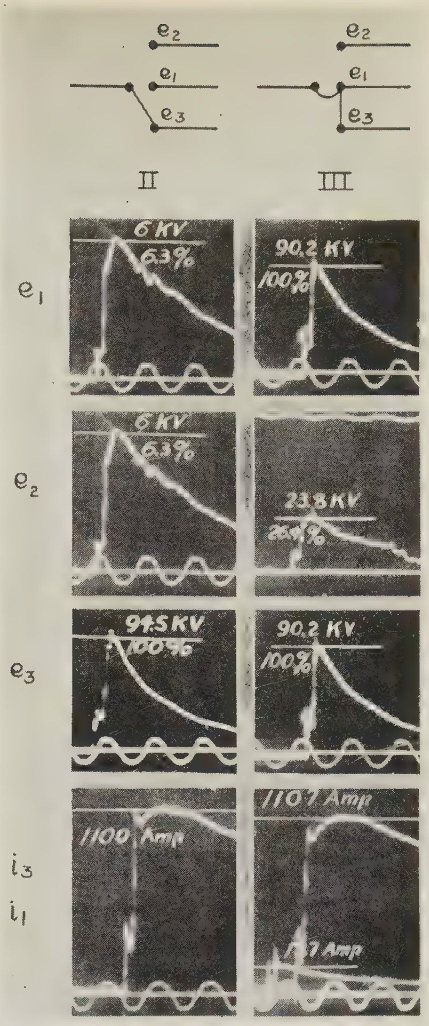
Discussion

In seeking evidence from these tests in support of the multi-velocity theory, perhaps the most conclusive is that shown in Fig. 4. According to the conventional theory of traveling waves there is no current on an isolated conductor—it merely floats in the electrostatic field of adjacent conductors and takes on the corresponding potential, and therefore, the shape of an induced surge is an exact replica of the inducing surge. But according to the multi-velocity theory there are current-carrying wave components on an isolated conductor, and in general these components travel at different speeds. Now it was shown that under condition I on the insulated counterpoise the voltage surge is

$$e_3 = -0.185\, E_0(v_2) + 0.234\, E_0(v_3) = (0.049\, E_0)$$

When this surge reaches the end of the counterpoise, which was grounded through driven pipe grounds, it reflects negatively and returns to the starting end of the counterpoise. The fast wave by that time has separated from its slower companion and so appears on Fig. (4I) as a positive bump.





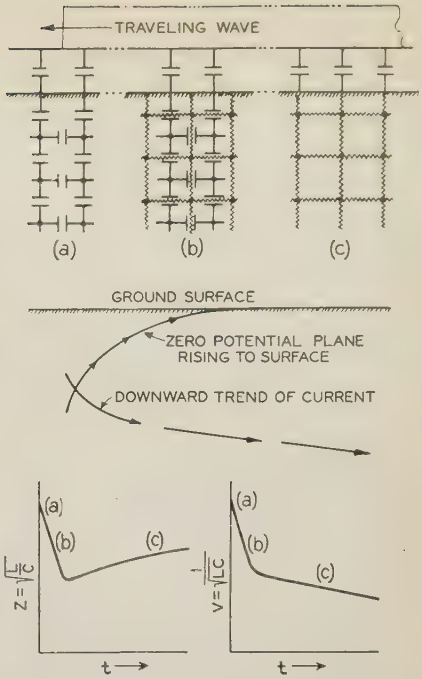


Fig. 13 (above). Phenomenon at the wave front

Top. Equivalent network at successive instants

Middle. Current and zero potential plane in the earth

Bottom. Variation of surge impedance and velocity

Fig. 11 (left). Oscillograms taken on buried counterpoise, for a low voltage surge of 15 kv

Fig. 12 (center). Oscillograms taken on buried counterpoise, for a 90-kv surge

But the slower wave is the larger of the 2, and therefore, dominates upon its arrival, reducing e_3 almost to zero.

Again in Fig. (4II) the positive bump is evident on e_1 and e_2, whose initial components were found to be:

$$e_1 = -0.244\ E_0(v_2) + 0.308\ E_0(v_3) = (0.064\ E_0)$$
$$e_2 = -0.244\ E_0(v_2) + 0.308\ E_0(v_3) = (0.064\ E_0)$$

Under condition II it is evident that the induced waves e_1 and e_2 register a positive bump at the same time when the main surge e_3 experiences a voltage drop and i_3, a current increase. This is rather conclusive evidence that the isolated conductors are not merely "floating in the electrostatic field of the main surge," but are conforming to the main surge *current*. This is all in complete agreement with multi-velocity theory, which predicted that the induced voltage from a counterpoise is due to the counterpoise current. Indeed, according to Appendix B

$$\frac{e_2}{e_3} = \frac{L_{23}}{L_{33}\ (1 + v_2/v_1)}$$

Thus the coupling factor is constrained by the limits

$$\frac{1}{2}\left(\frac{L_{23}}{L_{33}}\right) \leq \left(\frac{e_2}{e_3}\right) \leq \left(\frac{L_{23}}{L_{33}}\right)$$

or has no more than a 2:1 range as far as capacitance coefficients (which are included in the velocities) are concerned.

Under condition III the bump in e_2 is less than under condition II. This is because there are 2 inducing currents involved, i_1 and i_3, and due to reflection i_1 decreased when i_3 increased, but not so much, so that the net effect on e_2 is still a positive bump.

The multi-velocity components, therefore, are seen to be present and behaving in conformity with theory. The numerical checks are probably as good as can be hoped for in this kind of calculation; especially in a situation where the order of magnitude of some of the quantities involved is not very much greater than the order of magnitude of the test errors.

In many problems dealing with traveling waves it is permissible to ignore the phenomenon at and immediately following the wave front, but in studying the action of a counterpoise some cognizance should be taken of this behavior, since the major effect is confined to the first few microseconds. When the surge impedance for the insulated counterpoise was plotted as function of time by taking the instantaneous ratios of voltage to current from oscillograms with fast sweep it was observed that the impedance dropped sharply from a high to a minimum value within the first half microsecond, then increased slowly as shown in the bottom sketch of Fig. 13. It has already been remarked in this paper

that the average observed velocity decreases with the length of the counterpoise. In order to explain these changes in surge impedance and velocity the situation of Fig. 13 is envisaged. When the abrupt wave front first arrives at a given point the current distribution in the ground is governed by the capacitance of the earth, Fig. 13*a*, and thus the zero potential plane with respect to voltage images is at some depth below the surface. Consequently, since $Z = \sqrt{L/C}$ and $V = 1/\sqrt{LC}$ and the effective C is small on account of the depth of the zero potential plane, the surge impedance is high and the velocity is high. These starting values are designated as points a in Fig. 13. There then ensues a very fast transient at the end of which the resistance network dominates over the capacitance network, and the zero potential plane rapidly rises to the surface of the earth, while the current continues its relatively slow downward trend. Thus the end of this readjustment finds the effective C much increased, but with no material change in the effective L. Therefore, the surge impedance reduces to a minimum and the velocity to a lower value during this transition stage, designated by points b in Fig. 13. Thereafter the effective capacitance does not change, since the zero potential plane is already at the surface, but the current continues its downward displacement, thereby increasing the effective L, and thus causing the surge impedance to increase slowly and the velocity to decrease slowly. These effects, which are clear and definite for an insulated counterpoise, are masked by the leakage effect in the case of the buried counterpoise.

Conclusions

The conditions under which these tests were made were not conducive to the most accurate type of determination of the factors involved. The effects were not pronounced enough, and the test errors too erratic, to permit of any "rock-bound" conclusions; but the following facts seem to have been established.

1. The impedance of a buried counterpoise is a variable starting at a value equal to its surge impedance and ending at a value equal to its leakage resistance. The transition may require from 1 to 10 μsec, depending upon the length of the counterpoise and the earth resistivity. Propagation of surges on counterpoises is thus as much diffusion as traveling wave phenomena.

2. The coupling effect of a counterpoise depends primarily upon the position of the current images, and is not greatly dependent upon the capacitance relationships. The higher the earth resistivity and the greater the depth to the water level, the lower the current images and the higher the coupling.

3. The earth's surface may be considered the zero potential plane for voltage images of traveling waves.

4. Multi-velocity waves exist on a counterpoise, but the only one of importance is very slow, traveling at about 1/3 the velocity of light. The arrival of reflections may be estimated on that basis.

5. A new and accurate method for determining velocities on counterpoises has been devised (E. J. Wade). This method indicated that the initial velocity of the wave when it first enters the counterpoise is higher than its ultimate velocity. This is reasonable theoretically.

6. Due to the leakage the current in a counterpoise drops off rapidly and the front of the advancing wave is greatly flattened. For this reason the coupling effect vanishes at points a few hundred feet from the tower.

7. Counterpoises more than 200 to 300 ft long do not appear justifiable. If greater effect is desired it should be secured by a multiplicity of counterpoises of this length arranged radially. Very short counterpoises give rise to reflections and are therefore not so efficient as one long enough to be practically free of this source of additional voltage.

8. The multi-velocity theory appears to be adequate for numerical calculations as well as for a description of the mechanism of counterpoise action. But for routine design calculations a much simpler approximate method of analysis is sufficient.

Appendix A

The multi-velocity wave components on a 3-conductor system comprising a ground wire, line wire, and counterpoise are (see "The Counterpoise," by L. V. Bewley, *G. E. Rev.*, 1934, v. 37, p. 73–81):

$$\left.\begin{aligned} e_1 &= a_{11}f_1(x - v_1t) + a_{12}f_2(x - v_2t) + a_{13}f_3(x - v_3t) \\ e_2 &= a_{21}f_1(x - v_1t) + a_{22}f_2(x - v_2t) + a_{23}f_3(x - v_3t) \\ e_3 &= a_{31}f_1(x - v_1t) + a_{32}f_2(x - v_2t) + a_{33}f_3(x - v_3t) \end{aligned}\right\} \quad (1)$$

$$\left.\begin{aligned} i_1 &= Y_{11}f_1(x - v_1t) + Y_{12}f_2(x - v_2t) + Y_{13}f_3(x - v_3t) \\ i_2 &= Y_{21}f_1(x - v_1t) + Y_{22}f_2(x - v_2t) + Y_{23}f_3(x - v_3t) \\ i_3 &= Y_{31}f_1(x - v_1t) + Y_{32}f_2(x - v_2t) + Y_{33}f_3(x - v_3t) \end{aligned}\right\} \quad (2)$$

in which the velocities v_1, v_2, v_3 are given by the roots of

$$(I_{11} - v^{-2})(I_{22} - v^{-2})(I_{33} - v^{-2}) + I_{12}I_{23}I_{31} + I_{13}I_{32}I_{21} - (I_{11} - v^{-2})I_{23}I_{32} - (I_{22} - v^{-2})I_{13}I_{31} - (I_{33} - v^{-2})I_{12}I_{21} = 0 \quad (3)$$

and the a coefficients are (for $r = 1, 2,$ or 3)

$a_{11} = a_{12} = a_{13} = 1$ (arbitrarily)

$$\left.\begin{aligned} a_{2r} &= \frac{I_{21}I_{13} - I_{23}(I_{11} - v_r^{-2})}{I_{12}I_{23} - I_{13}(I_{22} - v_r^{-2})} = \frac{I_{31}I_{23} - I_{21}(I_{33} - v_r^{-2})}{(I_{22} - v_r^{-2})(I_{33} - v_r^{-2}) - I_{32}I_{32}} \\ a_{3r} &= \frac{-I_{12}I_{21} + (I_{11} - v_r^{-2})(I_{22} - v_r^{-2})}{I_{12}I_{23} - I_{13}(I_{22} - v_r^{-2})} = \frac{I_{21}I_{32} - I_{31}(I_{22} - v_r^{-2})}{(I_{22} - v_r^{-2})(I_{33} - v_r^{-2}) - I_{32}I_{23}} \end{aligned}\right\} \quad (4)$$

where, in general,

$$I_{rs} = (L_{1r}K_{1s} + L_{2r}K_{2s} + L_{3r}K_{3s}) \quad (5)$$

$$Y_{sr} = (K_{s1}a_{1r} + K_{s2}a_{2r} + K_{s3}a_{3r})v_r \quad (6)$$

The L's and K's being the inductance and capacitance coefficients.

If there are 2 ground wires in a horizontal plane, or 2 parallel counterpoises, then the inductances and electrostatic coefficients are to be calculated as for an equivalent single conductor. Thus for 2 ground wires 1 and 1′

$$L_{11} = \frac{2}{10^9}\log_\epsilon \frac{2\,h_1}{\sqrt{rm}} = \text{self inductance of the pair}$$

$$L_{12} = \frac{2}{10^9}\log_\epsilon \sqrt{\frac{aa'}{bb'}} = \text{mutual inductance of the pair to the line conductor}$$

where

$2\,h_1$ = height of ground wire from its image
r = radius of ground wire conductor
m = separation between ground wires
b = separation between ground wire 1 and line wire
a = separation between image of 1 and line wire
b' = separation between ground wire 1′ and line wire
a' = separation between image of 1′ and line wire

Similarly for a pair of counterpoises the electrostatic coefficients are likewise

$$p_{11} = 18 \times 10^{11}\log_\epsilon \frac{2\,H_1}{\sqrt{rm}}$$

$$p_{12} = 18 \times 10^{11}\log_\epsilon \sqrt{\frac{aa'}{bb'}}$$

where $2\,H_1$ is distance to the electrostatic image and R is the radius of the effective corona envelope.

If a lightning stroke of surge impedance Z and incident wave E strikes a tower having ground wire and counterpoise, and tower footing resistance R, then

$$f_1 = \frac{E_0}{\Delta}[(a_{32} - 1)\,Y_{23} - (a_{33} - 1)\,Y_{22}] = b_1E_0 \quad (7)$$

$$f_2 = \frac{E_0}{\Delta}\left[(a_{33} - 1)\, Y_{21} - (a_{31} - 1)\, Y_{23}\right] = b_2 E_0 \quad (8)$$

$$f_3 = \frac{E_0}{\Delta}\left[(a_{31} - 1)\, Y_{22} - (a_{32} - 1)\, Y_{21}\right] = b_3 E_0 \quad (9)$$

$$\Delta = \left[a_{32}\,(Y_{23} - Y_{21}) + a_{31}\,(Y_{22} - Y_{23}) + a_{33}\,(Y_{21} - Y_{22})\right] \quad (10)$$

$$E_0 = \frac{(2E)}{Z\left[\frac{1}{R} + \frac{1}{Z} + 2(Y_{11}+Y_{31})b_1 + 2(Y_{12}+Y_{32})b_2 + 2(Y_{13}+Y_{33})b_3\right]} \quad (11)$$

The equations of this appendix permit the calculation of the behavior of a counterpoise. Reflections up and down the tower have been ignored in accordance with the justifications given in original paper on this analysis. ("The Counterpoise," *G. E. Rev.*, 1934, v. 37, p. 73–81).

PERPENDICULAR COUNTERPOISE

If the counterpoise is perpendicular, the voltage equations are

$$e_1 = \frac{Y_{22}E_0(x - v_1t) - Y_{21}E_0(x - v_2t)}{(Y_{22} - Y_{21})} \quad (12)$$

$$e_2 = \frac{a_{21}Y_{22}E_0(x - v_1t) - a_{22}Y_{21}E_0(x - v_2t)}{(Y_{22} - Y_{21})} \quad (13)$$

$$E_0 = \frac{2E}{Z\left[\frac{1}{R} + \frac{1}{Z} + 2\,Y_{33} + 2\left(\frac{Y_{11}Y_{22} - Y_{12}Y_{21}}{Y_{22} - Y_{21}}\right)\right]} \quad (14)$$

$$\frac{1}{v^2} = \frac{(I_{11} + I_{22}) \pm \sqrt{(I_{11} - I_{22})^2 + 4\,I_{12}I_{21}}}{2} \quad (15)$$

$$\left.\begin{aligned} a_{21} &= (v_1^{-2} - I_{11})/I_{12} \\ a_{22} &= (v_2^{-2} - I_{11})/I_{12} \end{aligned}\right\} \quad (16)$$

$$\left.\begin{aligned} Y_{11} &= (K_{11} + a_{21}K_{12})v_1 \\ Y_{12} &= (K_{11} + a_{22}K_{12})v_2 \\ Y_{21} &= (K_{12} + a_{21}K_{22})v_1 \\ Y_{22} &= (K_{12} + a_{22}K_{22})v_2 \end{aligned}\right\} \quad (17)$$

$$\left.\begin{aligned} I_{11} &= L_{11}K_{11} + L_{12}K_{12} \\ I_{12} &= L_{11}K_{12} + L_{12}K_{22} \\ I_{21} &= L_{22}K_{12} + L_{12}K_{11} \\ I_{22} &= L_{22}K_{22} + L_{12}K_{12} \end{aligned}\right\} \quad (18)$$

Appendix B

The general analysis given in Appendix A is not only complicated and laborious (a complete set of computations requiring at least 2 days' work), but small errors made in the auxiliary constants may throw the final results quite far off the correct values. In this appendix a much shorter approximate method is developed which should suffice for ordinary calculations.

Referring to eqs 12 and 13 of Appendix A, the initial coupling factor between 2 conductors No. 1 and No. 2, the main surge being applied to No. 1 and the induced surge measured on No. 2, is

$$F_{12} = \frac{a_{21}Y_{22} - a_{22}Y_{21}}{Y_{22} - Y_{21}} \quad (19)$$

Now if one of these conductors lies on the ground surface, the mutual capacitance coefficients are zero ($K_{12} = K_{21} = 0$). On this basis, substituting eqs 15, 16, 17, and 18 into 19 and simplifying (it is quite a long job) there finally results

$$F_{12} = \frac{L_{12}}{L_{11} + \sqrt{(L_{11}L_{22} - L_{12}^2)\,\frac{p_{11}}{p_{22}}}} \quad (20)$$

or neglecting L_{12}^2 in comparison with L_{11} L_{22} and substituting

$$v_1 = \sqrt{\frac{p_{11}}{L_{11}}}, \quad v_2 = \sqrt{\frac{p_{22}}{L_{22}}} \quad (21)$$

the initial coupling factor may be written

$$F_{12} \cong \frac{L_{12}}{L_{11} + \sqrt{L_{11}L_{22}\,\frac{p_{11}}{p_{22}}}} = \left(\frac{L_{12}}{L_{11}}\right)\frac{1}{1 + (v_1/v_2)} \quad (22)$$

Now disregarding the multi-velocity wave components of Appendix A, a linear set of equations may be tentatively written between the voltages and currents on the system:

$$\left.\begin{aligned} e_1 &= Z_{11}i_1 + Z_{12}i_2 + Z_{13}i_3 = \text{ground wire} \\ e_2 &= Z_{21}i_1 + Z_{22}i_2 + Z_{23}i_3 = \text{line wire} \\ e_3 &= Z_{31}i_1 + Z_{32}i_2 + Z_{33}i_3 = \text{counterpoise} \end{aligned}\right\} \quad (23)$$

When multi-velocity components do not exist these are the exact canonical equations for traveling waves, but if multi-velocities do exist they are only approximate, however give close results for the first few microseconds. It remains to identify the coefficients. Obviously

$$\left.\begin{aligned} Z_{11} &= \sqrt{L_{11}p_{11}} = \text{surge impedance of ground wire} \\ Z_{22} &= \sqrt{L_{22}p_{22}} = \text{surge impedance of line wire} \\ Z_{33} &= \sqrt{L_{33}p_{33}} = \text{surge impedance of counterpoise} \end{aligned}\right\} \quad (24)$$

Suppose that only current i_1 is flowing. Then

$$\frac{e_2}{e_1} = \frac{Z_{21}}{Z_{11}} = F_{12}$$

and since both conductors are overhead, F_{12} must be computed by eq 19. Therefore

$$Z_{21} = Z_{11}F_{12} = Z_{11}\left[\frac{a_{21}Y_{22} - a_{22}Y_{21}}{Y_{22} - Y_{21}}\right] \quad (25)$$

Likewise, interchanging subscripts

$$Z_{12} = Z_{22}F_{21} = Z_{22}\left[\frac{a_{12}Y_{11} - a_{11}Y_{12}}{Y_{11} - Y_{12}}\right] \quad (26)$$

For the coefficients involving the counterpoise, the simplification of the type of eq 22 can be used, thus:

$$\left.\begin{aligned} Z_{13} &= Z_{33}F_{31} = Z_{33}\frac{L_{13}}{L_{33}}\frac{1}{1 + (v_3/v_1)} = L_{13}\left(\frac{v_1v_3}{v_1 + v_3}\right) \\ Z_{23} &= Z_{33}F_{32} = Z_{33}\frac{L_{23}}{L_{33}}\frac{1}{1 + (v_3/v_2)} = L_{23}\left(\frac{v_2v_3}{v_2 + v_3}\right) \\ Z_{31} &= Z_{11}F_{13} = Z_{11}\frac{L_{13}}{L_{11}}\frac{1}{1 + (v_1/v_3)} = L_{13}\left(\frac{v_1v_3}{v_1 + v_3}\right) \\ Z_{32} &= Z_{22}F_{23} = Z_{22}\frac{L_{23}}{L_{22}}\frac{1}{1 + (v_2/v_3)} = L_{23}\left(\frac{v_2v_3}{v_2 + v_3}\right) \end{aligned}\right\} \quad (27)$$

It is seen that $Z_{31} = Z_{13}$ and $Z_{32} = Z_{23}$.

Having established all the coefficients of eqs 23, these equations may be used directly. Assuming as in Appendix A that a lightning stroke of surge impedance Z and incident wave E strikes a tower having ground wire, line wire and counterpoise, and tower footing resistance R, then remembering that $i_2 = 0$ on the line wire:

$$\left.\begin{aligned} e_1 = E_0 &= Z_{11}i_1 + Z_{13}i_3 \\ e_3 = E_0 &= Z_{31}i_1 + Z_{33}i_3 \\ e_2 &= Z_{21}i_1 + Z_{23}i_3 \end{aligned}\right\} \quad (28)$$

But the total current from the stroke in terms of the incident wave E and the reflected wave E' is

$$\frac{E - E'}{Z} = \frac{2E}{Z} - \frac{E + E'}{Z} = \frac{2E}{Z} - \frac{E_0}{Z} = 2(i_1 + i_3) + \frac{E_0}{Q} \quad (29)$$

Solving for i_1 and i_3 from eq 28 and substituting in eq 29 there results

$$\left.\begin{aligned} i_1 &= E_0\left(\frac{Z_{33} - Z_{13}}{Z_{11}Z_{33} - Z_{13}^2}\right) = b_1E_0 \\ i_3 &= E_0\left(\frac{Z_{11} - Z_{13}}{Z_{11}Z_{33} - Z_{13}^2}\right) = b_3E_0 \\ E_0 &= \left(\frac{2E}{1 + 2Z\,(b_1 + b_3) + Z/R}\right) \end{aligned}\right\} \quad (30)$$

Hence substituting in eq 28

$$\left.\begin{aligned} e_1 = e_3 = E_0 &= \frac{2E}{1 + 2Z\,(b_1 + b_3) + Z/R} \\ e_2 = (Z_{21}b_1 + Z_{23}b_2)E_0 &= \frac{2E\,(Z_{21}b_1 + Z_{23}b_2)}{1 + 2Z\,(b_1 + b_3) + Z/R} \end{aligned}\right\} \quad (31)$$

Appendix C

In order to approximate the effects of the transition of the impedance of a counterpoise from its initial condition of surge impedance to its final condition of leakage resistance, the following method of analysis appears to have some merit. Assume the leakage resistance $R_3 = 1/gl$ to be concentrated at the end of a counterpoise of surge impedance, Z_3, and length T (to be defined later). Then successive reflections will eventually supplant Z_3 with R_3, and the problem reduces to that of computing these reflections. The time T is to be chosen so that the transition occurs in the required length of time, either as estimated from tests or as calculated from the following formula:

$$Z_3(t) = \frac{1}{gl\left\{1 - \sum_{s=1}^{\infty} \frac{8\epsilon^{-\alpha t}}{(2s-1)^2\pi^2}\left[\cos \omega_s t + \left(\frac{g}{4\omega_s C} - \frac{\omega_s C}{g}\right)\sin \omega_s t\right]\right\}} \qquad (32)$$

where

$$\omega_s = \frac{1}{2}\sqrt{\frac{(2s-1)^2\pi^2}{LC\,l^2} - \frac{g^2}{C^2}} \cong \frac{(2s-1)\,\pi}{2l\sqrt{LC}}$$

$$\alpha = g/2C$$

assuming $(g/\omega_s C)$ to be a small quantity, this reduces to

$$Z_3(t) = \frac{1}{gl\left\{1 - \epsilon^{-\alpha t}\sum_{s=1}^{\infty}\left[\frac{8\cos \omega_s t}{(2s-1)^2\pi^2} - \frac{4}{gl}\sqrt{\frac{C}{L}}\,\frac{\sin \omega_s t}{(2s-1)\pi}\right]\right\}} \qquad (33)$$

The first term under the summation sign is a triangular wave, and the second term a rectangular wave. Therefore it is easily seen that

$$\left.\begin{aligned} Z_3(t) &= \frac{1}{gl} \text{ at } t = \infty \\ Z_3(t) &= \sqrt{\frac{L}{C}} \text{ at } t = 0 \end{aligned}\right\} \qquad (34)$$

Thus if g, L, C of the counterpoise are known, $Z_3(t)$ may be computed and the time of transition from $\sqrt{L/C}$ to $1/gl$ readily found. The transition is brought about by the presence of the term $\epsilon^{-\alpha t}$. Therefore considering the transition as essentially complete when $\epsilon^{-\alpha t} = 0.05$, it follows that

$$t = \frac{3}{\alpha} = \frac{6C}{g} = \text{time of transition}$$

Now consider any set of wave components (f_1, f_2, f_3) on the ground wire, line wire, and counterpoise, in accordance with eqs 1 and 2 of Appendix A. When these waves reach the end of the counterpoise they will give rise to reflections (f_1', f_2', f_3') and transmitted waves (f_1'', f_2'', f_3'') and the transition point equations become

$$\left.\begin{aligned} e_1 + e_1' &= e_1'' \\ e_2 + e_2' &= e_2'' \\ e_3 + e_3' &= e_3'' \\ i_1 + i_1' &= i_1'' \\ i_2 + i_2' &= i_2'' \\ i_3 + i_3' &= i_3'' = e_3''/R_3 \end{aligned}\right\} \qquad (35)$$

From these the new components $(f_1', f_2', f_3', f_1'', f_2'', f_3'')$ may be determined. Now regarding the reflected waves (f_1', f_2', f_3') as new incident waves (dropping the primes) approaching the tower, an exactly similar set of equations to those above obtain, except that R_3 is now to be replaced by the resistance of the tower footing and the lightning stroke surge impedance in parallel, that is the last equation becomes

$$i_3 + i_3' = i_3'' = e_3''\,(R + Z)/RZ \qquad (36)$$

Thus it is possible to calculate the effect of the transient impedance of the counterpoise as a problem in successive reflections. But the work involved is so excessive that the approximation given in the text appears to be sufficiently accurate under the circumstances.

Toward the Making of a Profession

(*Continued from page 1148*)

ondary, perhaps a minor, function. It has wisely chosen to be the inspirer rather than the policeman of the profession. The intangibles of the spirit, the creating of an atmosphere, a tone, a fellowship, have far outweighed the letter of the law. In its contributions to public welfare, the Institute has wisely contented itself to work through the most inclusive agencies of the profession, the American Engineering Council, the national and international standardizing agencies, and most recently the E.C.P.D.

Relation of the Institute to the Modern State

In conclusion, only a hint can be given of the significant contribution of the Institute to the growing and evolving idea of a profession as a functional element in the complex of social organisms we call the modern state. The traditional fabric of society with its political and geographical strands is breaking apart under the stress of a complex life. In its place we see emerging the modern conception of the corporative state, a society in which the constituent units are not parties or political subdivisions, but functional groups, such as trade associations, labor unions, consumers' coöperatives, professional guilds, agricultural groups, and the like. The idea which underlies much of our democracy and in which Jefferson and his disciples so firmly believed, that the citizenry acting collectively would transcend their wisdom and intelligence as individuals, is sadly discredited. Too often the reverse is all too evident in political life. In professional bodies such as our own the idea of collective superiority has been vindicated; as a group we tend to act on a higher plane of idealism and of devotion to the common good than as individuals.

The future of society appears to depend more and more upon the vitality of such functional groups. Our greatest concern may well be to extend professional ethics and ideals to the wider areas of industrial and public life. The Institute has seen no necessary antithesis between economic profit and social gain. In emphasizing the long-range or professional view, as against the short-range or business view, it has sought to reconcile social profit with the profit of the balance sheet, to reconcile service and gain, to reconcile scientific progress with humanitarianism and to reconcile the highest stimulation of individual achievement with the widest distribution of social benefits. Before its members it has upheld the ideal of progress through sharing, rather than beating the game. In the larger concerns of society, as well as in the activities and relations of its thousands of individual members, the Institute has kept the faith, not alone in the letter that killeth, but even more in the spirit that maketh alive.

Characteristics and Uses of the Carbon Arc

The high efficiency of the carbon arc, the flexible and uniform quality of radiation it provides, and its extremely high intrinsic brilliancy give it a prominent place in the broad field of illumination. For applications in which a powerful light must be obtained from a source of small dimensions, it is unsurpassed. Characteristics of the various types of carbon arcs and their applications are outlined in this paper.

By
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THE CARBON ARC has passed through many interesting phases of development influenced by many factors of varied character. In early types, the street lamps of the "gay nineties," solid electrodes of coke composition, usually copper coated, were burned without protection from the air. Subsequent enclosure to prolong the burning period called for a reduction of the ash content of the electrodes and led to the development of the lampblack carbon. Steadiness of the light was improved greatly by the introduction of a center core of softer neutral composition which stabilizes the arc stream and prevents it from shifting about the rim of the crater. Further improvement was effected for certain types of lamps by the introduction of a metal coated negative carbon considerably smaller in diameter than the positive carbon.

Neutral Core Carbon Arc

Light from the solid or neutral core carbon arc operated on direct current comes almost entirely from the crater of the positive carbon. Little light is emitted from either the arc stream or the tip of the negative carbon. The light has a bluish tint with a strong band of ultra-violet radiation just outside the visible range. The energy distribution through the visible and ultra-violet range is shown in Fig. 1. In Fig. 2 is reproduced a photograph of the direct current arc with neutral cored positive electrode operated in the position shown in Fig. 4. This illustration clearly shows the positive crater as the principal source of light, and its brilliancy indicates the reason for the early popularity of this light source in motion picture projection.

The relatively high output of blue, violet, and ultra-violet radiation gave the carbon arc early popularity as an artificial source of illumination for photography, the emulsions then in use having little or no sensitivity to yellow, orange, and red. The carbon arc also attained extensive use in blue printing and photo-engraving, and the high-current direct-current arc was used by Finsen in his pioneer work in artificial light therapy.

The alternating current arc with neutral cored carbons is not as efficient as the direct current arc for, while the craters of the carbon electrodes are still the principal sources of light, their brilliancy, as may be seen from Fig. 3, is far less than that of the positive crater of the direct current arc.

In earlier applications of the carbon arc to motion picture projection, an inclined vertical "trim" was used as indicated in Fig. 4. The condenser lens in these lamps picks up a solid cone of light of approximately 45 deg. The crater is formed partially on the side of the carbon so as to present as large an effective area as possible to the condenser lens. Considerable attention on the part of the projectionist is required to maintain the proper crater formation and position

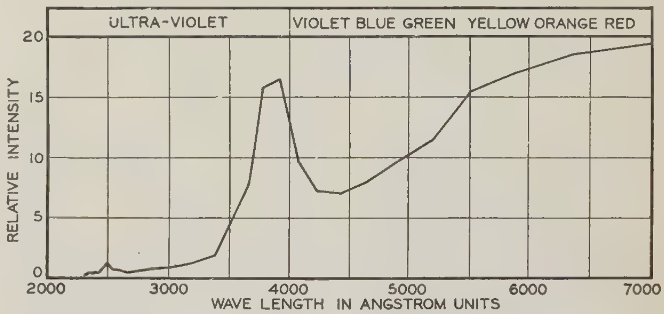


Fig. 1. Spectral energy distribution from neutral core carbon arc

Fig. 2. Direct-current neutral-core carbon arc

Fig. 3. Alternating-current neutral-core carbon arc

Full text of a paper recommended for publication by the A.I.E.E. committee on production and application of light, and scheduled for discussion at the A.I.E.E. winter convention, New York, N. Y., Jan. 22–25, 1935. Manuscript submitted June 20, 1934; released for publication July 5, 1934. *Not published in pamphlet form.*

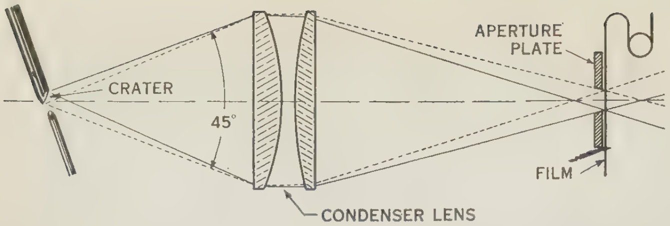
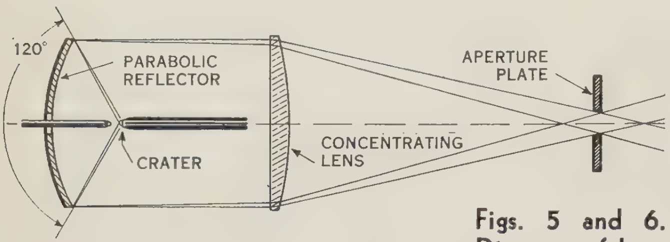
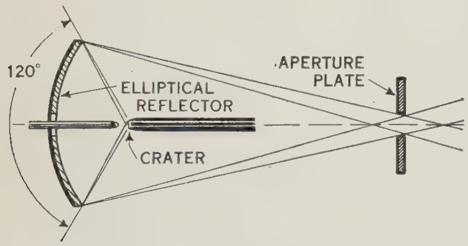


Fig. 4. Diagram of old type low-intensity direct-current projector lamp





Figs. 5 and 6. Diagrams of low-intensity direct-current reflecting arc lamps with parabolic mirror (above) and elliptical mirror (left)

in this type of lamp. In large theaters, positive carbons as large as $1^1/_8$ in. in diameter have been used with $^{17}/_{32}$-in. copper coating negative carbons and arc currents as high as 140 to 150 amp. The low intensity carbon arc still is used in searchlights for spectacular illumination, such as those at Niagara Falls and "A Century of Progress" exposition.

Direct-Current Low-Intensity Reflector Arc

Development of the reflector arc lamp added greatly to the efficiency of the low-intensity neutral-cored carbon arc in motion picture projection, increasing the light pick-up from a solid angle of 45 deg to one of approximately 100 deg. In this type of lamp, diagrammatically illustrated in Figs. 5 and 6, the carbon trim is horizontal with the crater of the positive carbon directly facing the mirror, thus exposing its full area to the optical system and at the same time simplifying the problem of the automatic control. At arc currents of 28 to 42 amp with positive carbons 12 or 13 mm in diameter, the direct-current low-intensity reflector arc provides a sufficient intensity of screen illumination for theaters of considerable size. More lamps of this type than of any other are used in motion picture theaters today. These lamps usually are operated from the standard voltage line through a transformer and rectifier or a motor generator set. The arc voltage is usually about 55 volts in this type of lamp.

The intrinsic brilliancy of the crater in the low-intensity neutral-cored carbon arc is limited by the vaporization temperature of carbon which is 4,126 deg K. When this temperature has been reached, further increase in arc current will increase the crater area and the rate of carbon consumption, but cannot increase the intrinsic brilliancy of the crater any more than the boiling point of water in open air can be raised by applying more heat. Light from this arc approaches pure white in color, but retains a definite tinge of yellow.

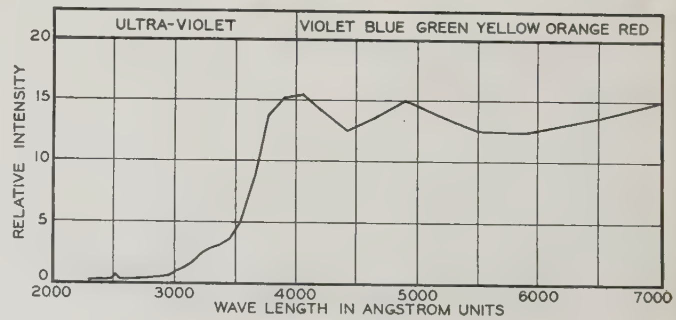
The Flame Arc

Introduction of flame supporting minerals in the cores of carbon electrodes transfers the principal source of light from the tips of the carbons, as in the neutral cored carbon arc, to the flame like arc stream, and provides a much longer arc than that between neutral cored carbons. There is little difference in the appearance, behavior, or output of the flame arc on direct current or alternating current. Figure 7 shows a photograph of an alternating current flame arc. The intrinsic brilliancy of the flame is relatively low, but, because of its size, it gives off a large volume of light and is a very efficient source of radiation. For like reason certain types of flame arcs are highly efficient sources of ultra-violet radiation.

An important characteristic of the flame arc is its flexibility, that is, the possibility of modifying the quality of the light by the choice of flame supporting materials in the core. In Fig. 8 is shown the energy distribution for the white flame carbon arc, the core of which contains minerals of the rare earth group, particularly cerium. By comparison of this curve with Fig. 1 it may be noted that the emission of

Fig. 7. Alternating current flame arc

Fig. 8 (below). Spectral energy distribution from white flame carbon arc



radiant energy in the visible range is increased greatly by this modification of the core composition and that the intensity of radiation is approximately the same in all primary color bands. The resultant light is bluish white, closely resembling daylight. This resemblance is also apparent in the spectrum of this arc which, like that of the sun, is practically a continuous band.

Carbons having polymetallic cores containing several metals including iron, nickel, and aluminum (know commercially as the "C" type) give less visible light than the white flame carbon, but much greater ultra-violet output as may be seen from Fig. 9. Strontium, Fig. 10, increases the red and infra-red emission from the arc with slightly lower ultraviolet output than that from the cerium cored carbon.

The white flame carbon arc finds extensive application in photography, where its light is considered photographically equivalent to daylight. It is used more largely in photo-engraving than any other light source. In light therapy a similar carbon known as the "Sunshine" carbon is used extensively where it is desired to duplicate artifically the physiological effects of natural sunlight. The "C" type and the strontium cored "E" type carbons likewise find extensive therapeutic use where emphasis on the ultraviolet or the infra-red bands of radiation is desired.

There is increasing use of the flame arc in industrial and photochemical processes such as accelerated testing of paints and dyes, the processing of certain materials, such as linoleum, patent leather, and tobacco, and the rapidly extending irradiation of milk for the purpose of increasing the vitamin *D* content.

The low-intensity alternating-current white-flame arc has found limited application in small motion picture theaters where direct current is not available; but the superiority of the direct-current low-intensity reflector arc, operated from a suitable rectifier or motor generator set, has given it preference over the former type for projection purposes. Reference will be made later to a recent development that promises to modify greatly projection practice in theaters of small and intermediate sizes.

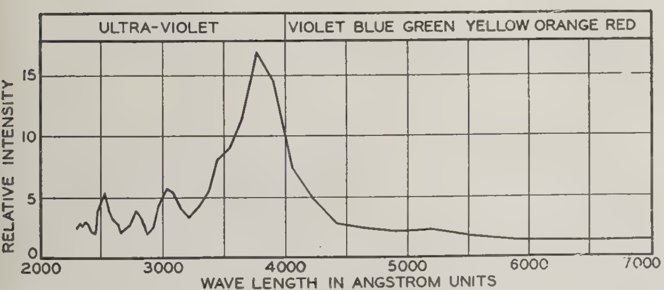


Fig. 9. Spectral energy distribution from "C" type carbon arc; these carbons have polymetallic cores containing iron, nickel, and aluminum

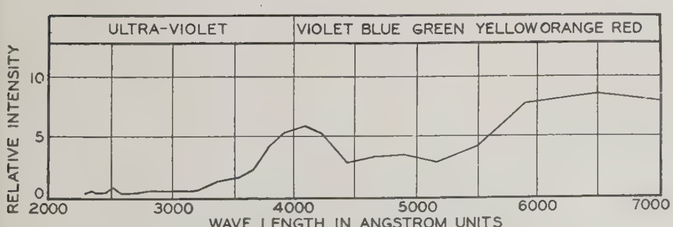
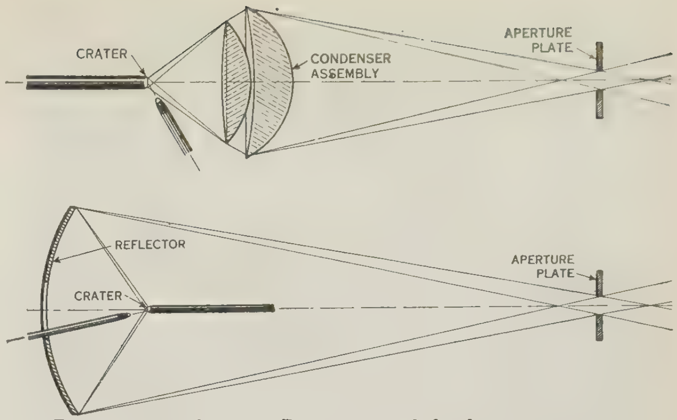


Fig. 10. Spectral energy distribution from "E" type carbon arc; these carbons have strontium cores



Figs. 11 and 12. Diagrams of high intensity arc lamp: (above) condenser type; (below) reflector type

The various types of lamps using flame type carbons embrace a wide range of arc conditions. Arc currents from 6 to 100 amp or more are used, and arc voltages from 25 to 60 volts. The large lamps most popular in industrial applications and light therapy at the present time are operated at 60 amp and 50 volts on alternating current, and at 50 amp and 60 volts on direct current.

Direct-Current High-Intensity Arc With Rotating Positive Carbon

Development of the high-intensity direct-current arc overcame the limitation of intrinsic brilliancy referred to in the discussion of the direct-current low-intensity arc. The positive electrodes of the direct-current high-intensity arc are operated at current densities much higher than those of the low intensity arc—450 to 860 amp per square inch (70 to 133 amp per square centimeter) for the former in comparison with 120 to 200 amp per square inch (18.5 to 31 amp per square centimeter) for the latter. Cored positive carbons 9 to 16 mm in diameter without metallic coatings are operated with copper coated negative carbons of smaller diameter at arc currents ranging from 60 to 190 amp, the arc voltage ranging from 45 to 90 volts.

In the condenser type high-intensity arc lamp, as indicated in Fig. 11, the positive carbon is held in a horizontal position with its crater directly facing the condenser assembly. Since the current density in the carbon is very high and the high efficiency of this type of arc is dependent on the maintenance of a well-formed cup-like crater, the positive carbon is allowed to project but a short distance from the holder and is rotated continuously while the arc is burning. The negative carbon is set at an angle to the positive, usually 40 to 60 deg below the horizontal. The feeding mechanism is designed to advance both carbons as they are consumed and should be adjusted to feed the positive carbon forward at

Fig. 13. High-intensity direct-current arc, front and side views

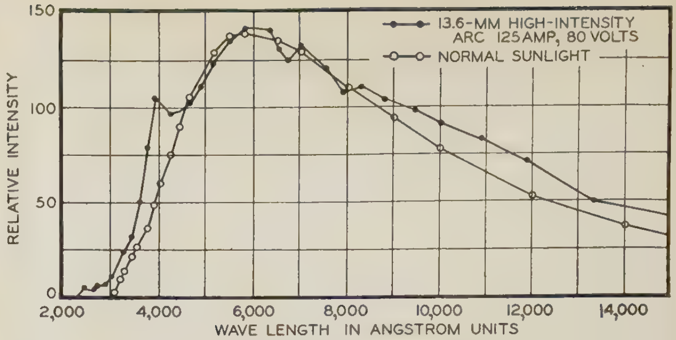
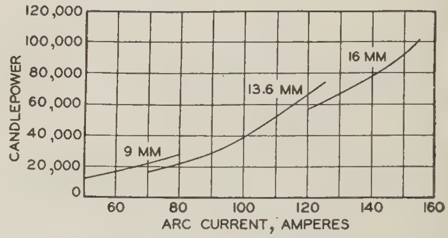


Fig. 14. Spectral energy distribution from high-intensity direct-current arc compared with that from normal sunlight

Fig. 15. Candle power of crater light from high intensity arc for carbons of 3 different sizes



the same rate it is being burned, thus maintaining the crater at a fixed position in relation to the condenser and to the point of intersection with the axis of the negative carbon. The rate of feed of the negative carbon is also adjustable relative to that of the positive, and when properly adjusted maintains an arc of uniform length.

The reflecting principle of light concentration has been applied also to the high intensity arc. In all high intensity reflecting arc lamps the positive carbon is held in a horizontal position. The negative carbon also may be held horizontally or inclined to the positive, as shown in Fig. 12.

Light from the high intensity arc emanates from 2 distinct sources, the crater and the tail flame. The tail flame produces about 30 per cent of the total light from this type of arc, but is of little value for most applications since its size, shape, and position prevent its being focused accurately. Therefore, a consideration of the characteristics of the high intensity arc is concerned chiefly with the crater light from the positive carbon. The whiteness and intrinsic brilliancy of this crater light exceeds that of incandescent carbon volatilized at atmospheric pressure. Evidently its source is something more than the solid tip of incandescent carbon since its color and brilliancy indicate a temperature of about 5,500 deg C. This intensified light can be considered as coming from a portion of the luminous gases of the flame material retained in the crater of the positive carbon by the force of the negative arc stream. This explanation may not accord with physical facts but it aids the imagination in visualizing the reason for the remarkably high intrinsic brilliancy of the high intensity carbon arc as compared with other artificial sources of illumination.

Maximum intrinsic brilliancy from the high intensity arc is attained by adjusting the position of the negative carbon so that the negative arc stream compresses within the crater of the positive carbon a substantial portion of the brilliantly luminescent vapors emanating from that point. This produces a bluish white light of very high candle power and much brighter than can possibly be obtained from incandescent carbon alone. A photograph of the direct-current high-intensity arc is reproduced in Fig. 13.

The energy distribution curve for a typical high intensity carbon arc is shown in Fig. 14. On this is superposed the energy distribution curve for normal sunlight. Radiation from the arc as here measured is the radiation from the positive crater only since in most applications of this type of arc the crater light is all that can be utilized. These curves show the striking similarity between this light source and natural sunlight through the entire range of the spectrum. The candle power of the crater light directly in front of the arc is shown in Fig. 15. As would be expected, the candle power increases with the current. When the same current is used with 2 different sized carbons of the same composition the smaller, that is, the one with the higher current concentration, gives the greater candle power.

The term "super high intensity arc" has been given to the arc produced by special 16-mm high-intensity carbons capable of carrying 195 to 200 amp and producing 40 to 60 per cent higher candle power than the ordinary 16-mm high-intensity carbon operated at 150 amp.

Motion picture projection in the larger theaters is the principal field of application for the high intensity arc. There are many other applications, however, including theater spotlights, motion picture studio sun arcs and rotary spots, army and navy searchlights, searchlights used for spectacular illumination, airport landing lights, and the famous Lindbergh beacon at Chicago.

Direct-Current High-Intensity Arc With Nonrotating Positive Carbon

The smallest direct-current high-intensity arc with rotating positive carbon in general use is the so-called "Hi-Lo" projection lamp which uses a 9-mm

Table I—Arc Conditions for Direct-Current High-Intensity Arc with Nonrotating Positive Carbon

Carbon Diameter, mm: Postive	Carbon Diameter, mm: Negative	Arc Current, Amperes	Arc Voltage	Current Density in Positive Carbon: Amp per Sq In.	Current Density in Positive Carbon: Amp per Sq Cm
6	5	35–40	28–35	800–910	124–141
7	6	45–50	29–36	755–840	117–130
8	7	60–65	30–37	770–835	119–129

Table II—Arc Conditions for Alternating-Current High-Intensity Arc

Carbon Diameter, mm	Arc Current, Amperes	Arc Voltage	Current Density: Amp per Sq In.	Current Density: Amp per Sq Cm
6	40–45	18–24	910–1,025	141–159
7	60–65	23–26	1,005–1,090	156–169
8	75–80	24–29	960–1,025	149–159

positive carbon operating at 60 to 65 amp and 45 to 50 volts. A rather large interval exists between the screen illumination available from this lamp and that practicable with the low intensity reflector arc used in the majority of small theaters. There is also a marked difference in the color of light from these 2 types of arcs. The low intensity arc gives a yellowish white light whereas the high intensity arc gives a snow white light generally considered more desirable for the projection of motion pictures. To bridge this gap and provide for the small theater screen illumination of high intensity, quality, and brilliancy, a metal coated carbon of small diameter has been developed to operate at an intermediate current. The carbons for this small high intensity arc have been so designed that the positive carbon does not need to be rotated and the negative can be coaxial with the positive. The carbons are protected from oxidation and their electrical resistance reduced by the metal coating making it practicable to hold the carbon at any convenient distance from the arc. Arc current and voltage ranges for the standard size trims are indicated in Table I.

Most efficient operation of this nonrotating direct-current high-intensity arc with its short arc length and low voltage calls for a motor generator set of not more than 50 to 55 volts rating. It should be possible for designing engineers to provide a generator for this purpose of such characteristics that no ballast resistance will be required in series with the arc.

Alternating-Current High-Intensity Arc

Operation of a direct current arc of any type from an alternating current power circuit requires the use of a motor generator set or a transformer and rectifier. The development of an alternating-current high-intensity carbon arc permits operation through a suitable transformer directly from the alternating current power line thus eliminating all rotating intermediate apparatus as well as the heavy power loss in ballast resistance. This provides a very efficient source of projection light. The alternating-current high-intensity arc, together with the direct-current high-intensity arc with nonrotating positive carbon, promise to supersede to a very large extent the direct-current low-intensity reflector arc which at present is used in approximately 60 per cent of the motion picture theaters in the United States. The alternating-current high-intensity arc is essentially a development from the ordinary flame arc obtained by increasing the current and reducing the voltage usually used with the ordinary flame arc, the intrinsic brilliancy of which is too low to be suitable for projection. Light emitted by the white flame arc at currents up to 30 or 35 amp increases directly as the voltage, but as the square of the current. The rate of increase of light with increased current decreases for currents of more than 30 to 35 amp until at very large currents the rate of light increase becomes equal to the rate of current increase. By increasing the current but decreasing the arc length and voltage, the arc becomes steadier and the sources of light are concentrated into smaller volume near the electrode tips.

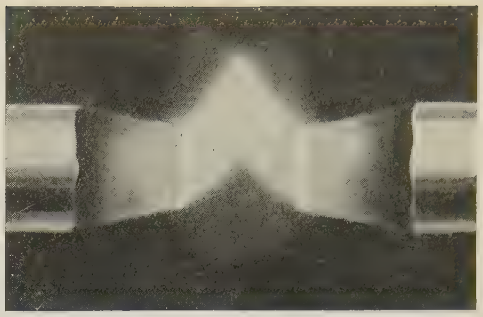


Fig. 16. Alternating-current high-intensity arc

The alternating-current high-intensity arc does not have the same crater formation as the direct-current high-intensity arc with rotated positive carbon, but the light has the brilliant snow white quality characteristic of all high intensity arcs. The appearance of this arc is shown by the photograph reproduced in Fig. 16.

Lamps designed for operation with alternating-current high-intensity carbons are of the reflector type. Both carbons are of the same diameter and are burned in a horizontal position without rotation. Metal coating provides high electrical conductivity and permits support of the carbons at a distance from the arc. Arc currents and voltages for most satisfactory operation are given in Table II.

Although practically all of the light projected onto the screen is picked up from the carbon facing the reflector and this carbon is of negative polarity during alternate half cycles, there is no noticeable flicker in the screen illumination. This is because the light is of almost equal intensity during both positive and negative half cycles. In this respect the alternating-current high-intensity arc differs materially from the alternating-current low-intensity arc, and resembles the arc from rectified alternating current as may be seen from the oscillograms reproduced in Figs. 17 and 18. It is apparent from Fig. 17 that the screen illumination from the low intensity arc during the negative half cycle is less than half the peak reached during the positive half cycle, while the high intensity arc shows very little

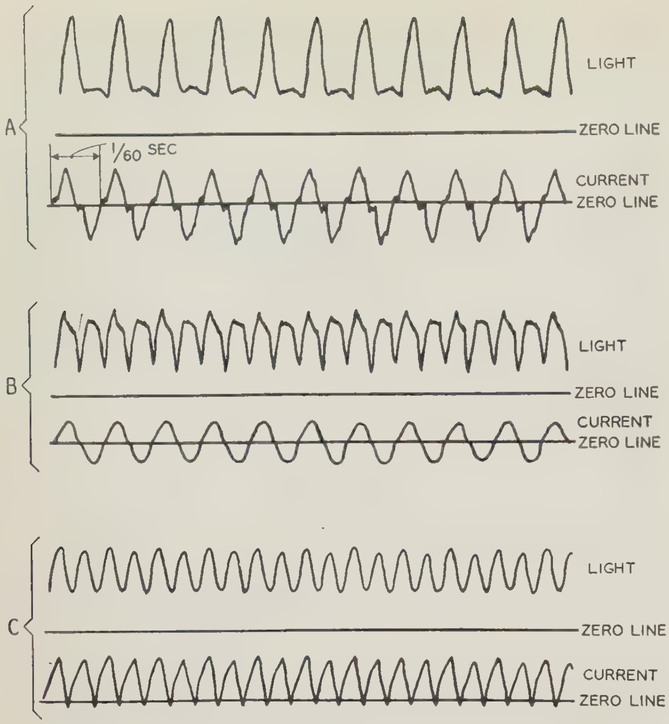


Fig. 17. Oscillograms of arc current and instantaneous light on projection screen without projector shutter running

A. Low-intensity 60-cycle alternating-current arc
B. High-intensity 60-cycle alternating-current arc
C. Low-intensity rectified-current arc

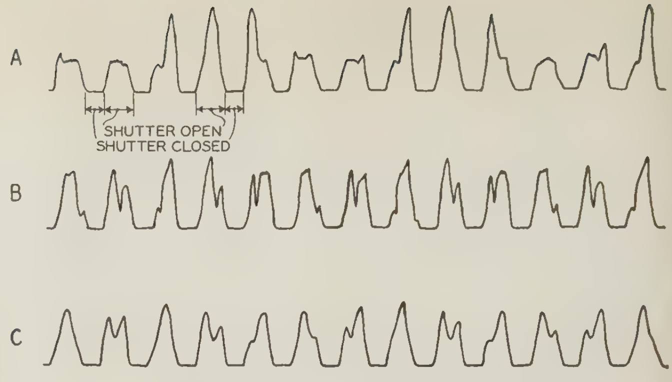


Fig. 18. Oscillograms of instantaneous light on projection screen with 2-blade projector shutter running at 1,440 rpm (film speed 90 ft per minute)

A. Low-intensity 60-cycle alternating-current arc
B. High-intensity 60-cycle alternating-current arc
C. Low-intensity rectified-current arc

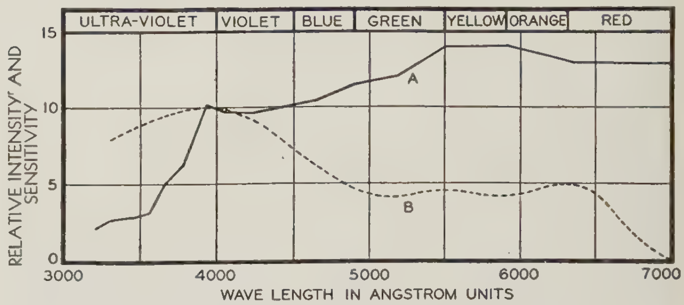


Fig. 19. Spectral energy distribution of 40-amp studio-carbon arc (A) and color sensitivity of supersensitive panchromatic motion picture film (B)

difference between positive and negative half cycles. Figure 18 indicates the flicker that results from the harmonic between the shutter speed and the circuit frequency with the low-intensity arc and the absence of a pronounced harmonic with the high-intensity arc.

A valuable feature of this arc and likewise of the direct-current high-intensity arc with nonrotating positive carbon is that the brilliant screen illumination made available to small theaters permits a level of general illumination that provides immediate confortable vision to those entering the theater. This is of decided advantage from the standpoint of safety as well as that of attracting patronage, and has heretofore been available only to the large theaters using powerful direct-current high-intensity projection lamps or to those "neighborhood" theaters small enough for the direct-current low-intensity arcs to provide a corresponding level of illumination.

At present, application of the alternating-current high-intensity arc is confined to motion picture projection, but its possibilities are not limited to this use and it undoubtedly will find other fields of application.

Improved Motion Picture Studio Carbon Arc

The effectiveness of a light source in photography is dependent upon the distribution of its radiant energy throughout the spectrum and upon the spectral sensitivity of the photographic emulsion. The plain carbon arc with only 17 per cent of its radiant energy in the visible and photographically effective ultra-violet range of the spectrum was satisfactory for the emulsions of an earlier day which were most sensitive to the blue, violet, and ultra-violet rays. Early panchromatic emulsions, while extending the range of sensitivity to all visible colors, were still low in sensitivity to yellow, orange, and red. A special type of flame carbon strong in orange and red emission was developed to meet the demands of that period for an efficient light source giving equal photographic effect for all colors. The development of present day supersensitive panchromatic emulsions, having much greater sensitivity to orange and red than the early types, calls for a light source of almost equal strength in all color bands; in fact, the color sensitivity of these emulsions is almost perfectly balanced to the radiant energy distribution of normal daylight.

An improved white flame photographic carbon recently has been developed to match the sensitivity of these latest photographic emulsions, thus giving the motion picture studios the advantages of speed and coolness which characterizes the use of the carbon arc in photography. More than 40 per cent of the radiation from this arc is photographically effective. This new electrode is a metal coated carbon 8 mm in diameter with a core composed of rare earth chemicals of the cerium group. Special lamps developed for use with this carbon in the studio operate silently with continuous and uniform feeding of the carbons. These lamps overcome the ob-

jections to noisy and jumpy operation which were raised against the old types of arc lamps when sound was introduced into motion picture productions.

The new studio carbon arc is operated on direct current at 35 to 40 amp with about $37^1/_2$ volts across the arc. At this current density, 450 to 510 amp per square inch (70 to 79 amp per square centimeter) and with the relatively short arc length employed, the arc departs from normal characteristics of the regular white flame arc and takes on many of the characteristics of the high-intensity arc; however, the crater formation in the positive carbon, while distinct, is not deep. The brilliant gas ball at the tip of the positive carbon consequently has a highly effective lateral emission.

This arc at 40 amp and $37^1/_2$ volts gives about 9,330 candle power in the horizontal direction. A twin arc (2 arcs in series) without reflector gives approximately 200,000 lumens at this current and arc voltage compared with 158,000 lumens for the regular white flame arc using 13-mm carbons under the same conditions. On a 115-volt circuit this represents an efficiency of 43.5 lumens per watt as compared with 34.4 lumens per watt from the ordinary white flame twin arc. The energy distribution curve at 40 amp and $37^1/_2$ volts is shown in Fig. 19 together with the color sensitivity curve of a modern panchromatic photographic emulsion. Radiant energy of this new carbon in the visual part of the spectrum is considerably greater than that of earlier types of flame carbons and shows a peak in that region where supersensitive films are least sensitive.

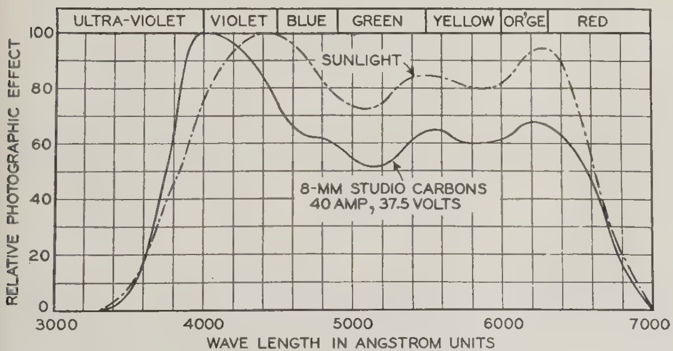


Fig. 20. Photographic effect from studio carbon arc compared with that from sunlight

Ordinates represent the product of transmission of glass lens, relative sensitivity of film, and spectral energy distribution of light source; values adjusted to give maximum equal to 100

Figure 20 shows the photographic effectiveness of the light from these carbons compared with that of natural sunlight. These curves take into account the spectral sensitivity of the photographic emulsion, the energy distribution of the light source, and the transmission factor of the camera lens. The close similarity to daylight in photographic effect is readily apparent from the figure.

This new carbon with the improved silent lamps designed for its use is restoring the popularity of the carbon arc in motion picture studios for black and white photography and has proved indispensable in the latest color process. Its high electrical and photographic efficiency makes it an equally desirable source of illumination for all kinds of photography.

Intrinsic Brilliancy

In many applications such as searchlights, spotlights, and motion picture projectors, it is essential that a powerful light be obtained from a source of small dimensions. In this respect the carbon arc is unsurpassed. The intrinsic brilliancy, that is, the candle power per square millimeter, for several types of arcs is given in Table III. For comparison, the intrinsic brilliancy of other light sources is included in the data presented.

Manufacture of lighting carbons requires a large investment in specialized equipment. The raw materials used are the purest commercial form of carbon available and the bonding agents are refined and distilled to required characteristics under conditions permitting very close control. Careful laboratory supervision at every stage of production is necessary to maintain the required standards in the finished product.

The carbon arc provides the basis for a ceaseless program of research. Steady improvements are being made in electrode manufacture as well as in lamp design. Longer electrode life, steadier operation, and higher electrical efficiency are being attained. New fields of application are being disclosed. Better adaptation to the many uses in which the arc now is applied is being achieved.

The high efficiency of the carbon arc as a source of visible and ultra-violet radiation, the flexible and uniform quality of radiation it provides, and its extremely high intrinsic brilliancy in relation to other artificial sources of radiant energy give the carbon arc a prominent and increasingly important place in the broad field of illumination.

Table III—Intrinsic Brilliancies of Light Sources

Light Source	Candle Power per Square Millimeter	Source of Data
Magnetite arc stream	6.2	W. R. Mott, National Carbon Co. Lab.
Flame arc stream	8.0	
900-watt special-tungsten-filament clear gas-filled bulb	26.6	International Critical Tables
Positive crater of cored, d-c low-intensity carbon arc	155– 175	*Journal*, Soc. of Motion Picture Engrs.
Crater of a-c high-intensity carbon arc	280	
Positive crater of nonrotating d-c high-intensity carbon arc	380	
Positive crater of rotating d-c high-intensity carbon arc	400– 800	
Positive crater of d-c "super high intensity" carbon arc	1,000–1,200	National Carbon Co. Lab.
Sun at zenith	920– 950	

Lightning Investigation on Transmission Lines—IV

Lightning currents ranging from about 4,000 to 63,000 amp in the towers of electric power transmission lines have been measured by the surge crest ammeter; of 64 readings obtained, all but 2 showed currents of negative polarity. This paper is the fifth in a series by the same authors reporting the results of a continued investigation of lightning effects on several typical transmission lines in different parts of the United States.

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THE YEAR 1933 was the eighth year of a continuous investigation of lightning effects on electric power transmission lines, carried on cooperatively by the General Electric Company and several operating power companies. This paper is the fifth of a series of A.I.E.E. papers by the same authors, reporting the results of this investigation.[1]

During 1933 the investigation was conducted mainly on the Wallenpaupack-Siegfried 220-kv line of the Pennsylvania Power and Light Company and the 132-kv Glenlyn-Roanoke (Va.) line of the Appalachian Electric Power Company (American Gas and Electric Company system). The field work dealt largely with the measurement of tower currents resulting from lightning discharges, for which purpose the surge crest ammeter was used almost exclusively. The conclusions of the preceding paper in this series are confirmed and restated in the first 3 paragraphs of the following summary of results:

1. The overhead ground wire definitely has been shown to be effective in reducing line tripouts.

2. Beneficial effects of low tower footing resistance have been shown by the data and analysis. A 220-kv line with normal insulation and conventional ground wire arrangement has operated for 5 years without flashover on towers with footing resistance 12 ohms or less.

3. The counterpoise is an effective means for securing low tower footing resistance.

4. In 64 readings obtained with the surge crest ammeter the tower current ranged from 4,000 to 63,200 amperes.

5. Practically all currents measured in transmission towers have been of negative polarity, indicating discharge from negative clouds and upward travel of the current in the stroke.

These data and accompanying theory indicate that lines may be designed for lightning conditions on the basis of correlating tower current, tower footing resistance, and line insulation strength.

Lines and Measuring Equipment

Wallenpaupack-Siegfried Line. This single circuit horizontally arranged line in eastern Pennsylvania extends from Wallenpaupack generating station to Siegfried, a distance of approximately 65 miles.[2] At Siegfried the line joins the Siegfried-Plymouth Meeting line and at Bushkill the line is tapped by the Bushkill-Roseland (N. J.) line.

For a distance of 27.2 miles the line is equipped with 2 overhead ground wires and for the remaining 37.5 miles it has no overhead ground wires. Of the ground wire section 2.6 miles are equipped with a continuous tower-to-tower counterpoise (buried copper cable) and 23.6 miles are equipped with radial counterpoises (4 buried copper cables each 50 ft long). One mile of the ground wire section has no special provision for reducing the tower footing resistance. Tower footing resistances in the tower-to-tower counterpoise section were reduced from 50–150 ohms to 1–1.5 ohms, and in the radial counterpoise section from 10–150 ohms to 5–75 ohms by the addition of the counterpoises.

All insulator strings were equipped with surge indicators and all towers with lightning stroke recorders and surge crest ammeter magnetic links,[3] placed 2 in. and 8 in., respectively, from the corner of the angle iron. Ten towers were equipped with lightning rods connected to the towers through resistors, lightning stroke recorders being shunted across the resistors. At 5 towers the overhead ground wires were insulated from the tower and connected to the tower through resistors shunted by lightning stroke recorders. Magnetic oscillographs were located at Wallenpaupack, Siegfried, and Roseland.

Glenlyn-Roanoke Line. This is a double-circuit vertical line in Virginia approximately 65 miles long with one overhead ground wire at the peak of the towers.[4] Tower footing resistance measurements were made between October and December 1931 with the ground wire detached; these ranged from 5 to 400 ohms. In May and June 1932 counterpoises were installed at 20 towers on the Roanoke end and 20 towers on the Glenlyn end. The footing resistances were checked at the Roanoke end and a 50-per cent reduction in resistance was found as compared with the measurements made in 1931.

The counterpoise at each tower consisted of 380 ft of $^{1}/_{16}$ x 2-in. galvanized iron strap. Two lengths of 150 ft each extended out from diagonally opposite tower legs, parallel with the line; 2 lengths each 40 ft long extended out at right angles to the line from the other 2 tower legs. The counterpoise conductors were buried approximately 18 in. under the

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surface of the ground where conditions permitted, and were bolted to the tower legs.

All 3 conductors of one circuit of the line were completely equipped with expulsion protective gaps.[5] All towers were equipped with lightning stroke recorders and surge crest ammeter magnetic links on one leg; 60 towers had magnets on all 4 legs. Each leg installation consisted of 2 magnetic links placed 1 in. and 7 in., respectively, from the corner of the angle iron. Twenty towers had tower top lightning rods connected to them through resistors shunted by lightning stroke recorders. In addition, the rods were equipped with surge crest ammeter magnetic links. Crossarms of 90 towers had surge crest ammeter magnetic links on the side not equipped with expulsion protective gaps, one link per crossarm. An automatic magnetic oscillograph was installed at Glenlyn to assist in determining the characteristics of the fault current.

Lightning Currents in Towers

In previous years tower currents have been determined by means of the lightning stroke recorder. This instrument measured the potential drop across a portion of the tower leg and this drop was translated into current by means of a laboratory calibration. Because of the uncertain cause of this potential drop, i. e., whether attributable to resistance, reactance, wave front, or a combination of these, it was not possible to make a reliable translation of the readings into current, and there is ample reason to believe that most of the readings of appreciable magnitude were too high. This instrument still is used; it is of value in checking polarity and in determining the location of the stroke.

The surge crest ammeter magnetic link responds only to the magnetic flux set up by the current passing down the tower leg and gives an accurate measurement of that current. Its only drawback is that oscillating or alternating current tends to demagnetize the links. However, theory and evidence seem to indicate that the lightning current itself is unidirectional. Correction readily may be made for the slight demagnetizing effect of the power frequency current that follows the lightning stroke current down the tower.

Table I gives the results of all the readings obtained on the Wallenpaupack-Siegfried line with the surge crest ammeter. These readings are divided into 3 groups. Items 1 to 10, inclusive, were for the section of line with overhead ground wires. No flashed insulators and no tripouts resulted (there was one surge indicator operation). The product of current and tower footing resistance for all readings was less than 400 kv.

The second group of readings, items 11 to 22, inclusive, was for sections of line having no overhead

Table I—Surge Crest Ammeter Readings, Flashovers, and Tripouts on Wallenpaupack-Siegfried 220-Kv Line During 1933

Item No.	Line Name	Tower No.	Footing Resistance, Ohms	Surge Crest Ammeter Reading, Amperes	Products $IR \times 10^{-3}$	Overhead Ground Wires	Flashed Insulators	Tripouts	No. of Insulator Units
1	WT	4–5	26	−10,000	260	Yes	No	No	14–16
2	WT	8–4	8	−23,000	184	Yes	No	No	14–16
3	WT	8–5	7	−27,000	189	Yes	No	No	14–16
4	WT	12–4	1	− 8,000	8	Yes†	No	No	14–16
5	SR	2–1	15	−24,000	360	Yes	SI	No	14
6	SR	2–4	10	−22,000	220	Yes	No	No	14
7	SR	2–5	5	−10,000	50	Yes	No	No	14
8	SR	4–2	8	−Trace*	32	Yes	No	No	14
9	SR	4–3	19	−Trace*	76	Yes	No	No	14
10	SR	4–4	19	−19,000	360	Yes	No	No	14
11	WT	27–6	58	−36,000	2,088	No	Yes	15	14–16
12	WT	28–1	45	−Trace*	180	No	Yes	15	14–16
13	WT	28–4	19	−12,000	228	Yes**	Yes	14	16
14	SR	7–1	17	−Trace*	68	No	Yes	5	14
15	SR	7–2	12	−12,000	144	No	Yes	5	14
16	SR	8–1	34	−12,000	408	No	Yes	7	14
17	SR	8–2	23	− 8,000	184	No	Yes	7	14
18	SR	9–3	28	−10,000	280	No	Yes	9	14
19	SR	19–3	45	−26,000	1,170	No	Yes	‡	14
	SR	24–1	48	None	None	No	Yes	10	14–16
20	SR	24–2	20	−12,000	240	No	Yes	10	14–16
21	SR	27–4	11	− 5,000	55	No	Yes	17	14–16
22	SR	31–3	34	−41,000	1,390	No	Yes	‡	14–16
23	SR	7–4	19	−Trace*	76	No	No	No	14
24	SR	8–4	20	−33,000	660	No	No	No	14
25	SR	9–2	15	−12,000	180	No	No	No	14
26	SR	20–1	30	−Trace*	120	No	No	No	14
27	SR	21–2	20	−30,000	600	No	SI	No	14
28	SR	26–2	20	+Trace*	80	No	No	No	14–16
29	SR	27–3	15	−Trace*	60	No	No	No	16
30	SR	31–4	14	− 8,000	112	No	SI	No	14–16
31	SR	32–2	13	−12,000	156	No	No	No	16
32	SR	32–3	27	− 4,000	108	No	No	No	14–16

* A trace corresponds to about 4,000 amp.
** Stroke probably occurred to open line beyond this tower (WT—28–4).
† Counterpoise installed.
‡ One of these flashovers caused tripout No. 11.
WT—Wallenpaupack tap. SR—Siegfried-Roseland line.
SI indicates surge indicator operation but no flashed insulators.
Insulator flashover voltages: 14 units, 1 x 5-μsec wave, 1,565 kv; 14 units 1.5 x 40-μsec wave, 1,265 kv; 16 units, 1 x 5-μsec wave, 1,775 kv; 16 units, 1.5 x 40-μsec wave, 1,425 kv.

Table II—Surge Crest Ammeter Readings, Flashovers, and Tripouts on Glenlyn-Roanoke 132-Kv Line During 1933

Item No.	Tower No.	No. of Towers Involved	Footing Resistance, Ohms	Tower Current* Amperes	Product IR × 10^{-3}	Flashed Insulators	Tripout	No. of Insulator Units**
1	12 G	1	80	−23,400	−1,900	Yes	No	12
3	21 G	3	140	−26,000	−3,640	Yes	Yes	12
18	53 G	5	35	−55,600	−2,000	Yes	Yes	12
5	61 G	1	17	−10,000	− 170	No	No	10
6	121 R	1	5	−10,000	− 50	No	No	12
8	16 G	1	18	− 9,600	− 170	No	No	12
9	79 G	1	10	−11,200	− 110	No	No	10
10	90 G	1	9	−63,200	− 570	No	No	10
11	91 G	1	8	−12,000	− 100	No	No	10
12	93 R	1	13	−11,200	− 145	No	No	12
13	94 R	1	22	− 6,800	− 150	No	No	10
21	62 G	1	6	−14,000	− 85	No	No	12
22	89 G	2	6	−10,800	− 65	No	No	10
23	114 R	2	20	−12,000	− 240	No	No	10
25	84 R	1	12	− 7,200	− 87	No	No	10
26	91 R	1	5	−22,600	− 113	No	No	10
28	104 R	2	13	−20,400	− 265	No	No	12
29	34 R	1	19	−18,000	− 340	No	No	10
31	88 R	1	12	− 9,600	− 115	No	No	10
32	83 R	1	12	−16,000	− 192	No	No	12
33	80 R	1	10	−12,800	− 128	No	No	12
35	80 G	1	20	− 8,800	− 175	No	No	10
36	101 R	1	10	+ 7,600	+ 76	No	No	10

* Where more than one tower is involved, data are given in this table for only the tower with highest current.
** $4^3/_4$-in. spaced units.
Insulator flashover voltages: 10 units, 1 x 5-μsec wave, 960 kv; 10 units, 1.5 x 40-μsec wave, 795 kv; 12 units, 1 x 5-μsec wave, 1,135 kv; 12 units, 1.5 x 40-μsec wave, 930 kv.

ground wires; flashover and tripout took place in all cases. Three of the products of current and resistance were high and of the order of the insulator flashover voltage for standard test waves; the other products were 400 kv or less. In this section a stroke to a conductor could result in insulator flashover regardless of the tower footing resistance. Only for strokes to towers would footing resistance determine flashover. In the ground wire section, however, for strokes to both towers and ground wires, flashover would be determined by the tower footing resistance.

The third group, items 23 to 32, inclusive, occurred in the section without overhead ground wires where there were no flashovers or tripouts (2 surge indicator operations were recorded). For all these readings, the product of current and resistance was less than 700 kv.

Tower currents varied from 4,000 to 40,000 amp. All currents were negative except item 28, which showed a trace of positive current.

In Table II are listed 23 lightning disturbances on the Glenlyn-Roanoke line. This line is equipped throughout with one overhead ground wire. A total of 32 registrations by the surge crest ammeter was recorded, but only one item in each group involving several towers is listed in Table II (that is for the tower showing highest current). Flashover of insulators occurred with the first 3 items and tripout with 2 of the 3 items. The product of current and tower footing resistance in these items exceeded the flashover voltage of the insulators with standard test waves. In the remaining items there was no flashover or tripout and all products of current and footing resistance were less than 600 kv.

Tower currents ranged from 6,800 to 63,200 amp, and all currents were negative except one, item 36, which indicated 7,600 amp of positive polarity.

Table III—Flashover of Towers, Insulator Assemblies, and Spillway Gaps on Wallenpaupack-Siegfried 220-Kv Line

Year	Flashed Towers	Flashed Insulator Assemblies	Spillway Gap Flashovers
1926	18	24	
1927	15	25	1
1928	100*	128*	0
1929	75	90	9
1930	50	56	4
1931	37	38	4
1932	17	22	2
1933	26	34	1
Total	338	417	21

* Includes carry-over from 1926 and 1927.
Spillway gap flashover voltages: 1 x 5-μsec wave 880 kv; 1.5 x 40-μsec wave 690 kv.

Table IV—Flashed Towers on Wallenpaupack-Siegfried 220-Kv Line Tabulated With Respect to Overhead Ground Wire Construction and Method of Grounding

			Overhead Ground Wires			
Year	Unknown	No Overhead Ground Wires	Standard Grounding	Tower-to-Tower Counter-poise	Radial Counter-poise	Total
1926		18				18
1927	11	4				15
1928	22	74	4*			100
1929	0	71	4	0		75
1930	0	45	3	0	2	50
1931	0	36	0	0	1	37
1932	0	15	0	0	2	17
1933	0	25	1	0	0	26
Total	33	288	12	0	5	338
Miles†		37.5	1.0	2.6	23.6	64.7

* One flashover on reduced insulation.
† Present mileage of each item. This mileage has changed from time to time as construction has been changed.

Table V—Tripouts Caused by Lightning on Pennsylvania-New Jersey 220-Kv Interconnection

Year	No. of Circuit Miles With O.G.W.	No. of Circuit Miles Without O.G.W.	No. of Tripouts With O.G.W.	No. of Tripouts Without O.G.W.	No. Tripouts per 100 Circuit Miles With O.G.W.	No. Tripouts per 100 Circuit Miles Without O.G.W.	Estimated Lightning Severity
1928	187	41	6	13	3.2	32	100
1929	187	41	5	37	2.7	90	130
1930	191	37	6	23	3.1	62	100
1931	263	37	5	20	1.9	54	70
1932	309	37	9	9	2.9	24	50
1933	309†	37*	5	14	1.6	38	70
Total			36‡	116‡			
Average					2.5	50	

O.G.W. = Overhead Ground Wires.
* All on Wallenpaupack-Siegfried line.
† Mileage distributed as follows: Wallenpaupack-Siegfried 27 miles; Siegfried-Plymouth 49 miles; Bushkill-Roseland 46 miles; Roseland-Plymouth 72 miles; Conowingo-Plymouth 114 miles.
‡ The locations of 49 tripouts were not known definitely, but these have been assigned to section with or without ground wires in accordance with correlated information.

Table VI—Effect of Tower Footing Resistance on Flashed Towers on Wallenpaupack-Siegfried 220-Kv Line, 1929–1933, Inclusive

Resistance Range, Ohms	No. of Towers Flashed	No. of Towers Total No.	Ratio Flashed to Total Towers
A. Overhead Ground Wire Section			
1— 12	0	36	0.00
13— 65	10	100	0.10
66—120	2	4	0.50
1—120	12	140	0.09
B. Section Without Overhead Ground Wires			
1— 10	14	14	1.00
11— 65	134	148	0.91
66—330	23	30	0.77
1—330	171	192	0.89

Flashovers and Tripouts as Affected by Overhead Ground Wires

Table III shows the number of flashovers on towers, insulator assemblies, and spillway gaps on the 220-kv Wallenpaupack-Siegfried line for 8 years, 1926 to 1933, inclusive. The spillway gaps are at the line terminals and are set at approximately 50 per cent of the flashover voltage of the line insulators.

Data for the 338 flashed towers shown in Table III are analyzed in Table IV with respect to the overhead ground wire construction of the line. It was not possible to classify 33 flashed towers; of the remaining 305, 288 were on the 37.5 miles without overhead ground wires and the remaining 17 occurred on the 27.2-mile ground wire section. None of the flashovers has occurred on the tower-to-tower counterpoise section since the counterpoise was installed, although 29 insulator assembly flashovers occurred in this section in the 3 years prior to installation of counterpoise wires. While the radial counterpoise does not show up as well as the tower-to-tower counterpoise, it must be remembered that the radial arrangement consists of only 200 ft of cable in 4 50-ft lengths, and the tower footing resistance is not nearly as low (5 to 75 ohms) as in the tower-to-tower counterpoise section (1 to 1.5 ohms). Also, of course, about 9 times as much line is equipped with the radial as with the tower-to-tower counterpoise.

Table V summarizes the tripout situation on the entire 220-kv Pennsylvania-New Jersey interconnection, consisting of approximately 346 miles of line. Tripouts are shown to be approximately 20 times as frequent on the line without overhead ground wires as on the lines with overhead ground wires.

Table VI shows the effect of tower footing resistance on tower flashover for the Wallenpaupack-Siegfried line during the 5-yr period, 1929–33, inclu-

Table VII—Lightning Tripouts on Typical Transmission Lines With Overhead Ground Wires

Company and Line	Kv	No. of Miles	No. of Insulator Discs	No. of Ground Wires	Height of Ground Wires Above Conductors at Tower	Distance Between Outside Conductors	Distance Between Ground Wires	No. of Tripouts	No. of Years	Tripouts per 100 Miles per Year
Pa. Power & Light Co. Wallenpaupack-Siegfried	220	27	14–16	2	10.5–11.5	45.3	22.5	4	6	2.47
Pa. Power & Light Co. and Philadelphia Elec. Co. Siegfried-Plymouth, P. P. & L. section	220	49	14	2	13	52.5	28	6	6	2.04
Siegfried-Plymouth, Phila. Elec. section	220		16	2	16	51	25.5			
Philadelphia Elec. Co. Conowingo-Plymouth (No. 1)	220	57	14	2	16	51	25.5	8	6	2.34
Conowingo-Plymouth (No. 3)	220	57	14	2	16	51	25.5	8	6	2.34
Public Service Gas & Elec. Co. Bushkill-Roseland	220	46	16–18	2	18	57	28.5	1	2	1.09
Public Service Gas & Elec. Co. Roseland-Plymouth	220	72	16–18	2	18	57	28.5	8	3	3.7
Pa. Water & Power Co. Safe Harbor-Westport	220	70	20*	2	26	56.5	42.25	1	2	0.7
Philadelphia Elec. Co. Philadelphia-Chester**	66	14	8*	2	11	17.25	17.25	1	16	0.45
N. Y. Power & Light Co. Greenbush-Pleasant Valley**	110	64	11	2	8.3	28	22	3	2.25	2.08
N. Y. Power & Light Co. N. Y. Edison Co. Pleasant Valley-Millwood**	132	40.5	12	2	11.75	30.5	36	2	2	2.47

* 5-in. spacing; other lines $5^3/_4$-in. spacing.
** Double-circuit vertical; other lines single-circuit horizontal arrangement.

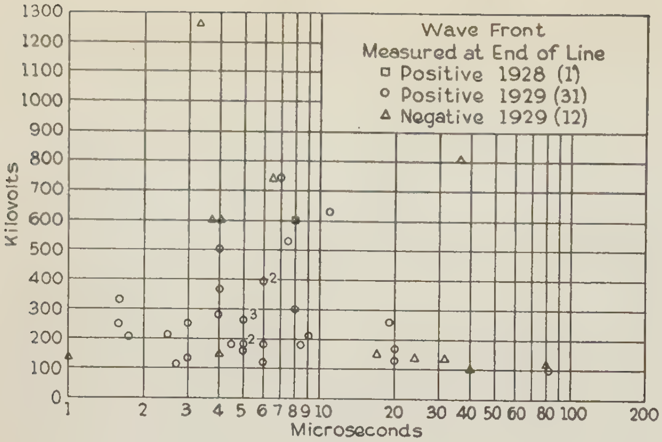

Fig. 1. Length of front of 45 waves caused by lightning on the 220-kv Wallenpaupack-Siegfried line as recorded at end of line by cathode ray oscillograph

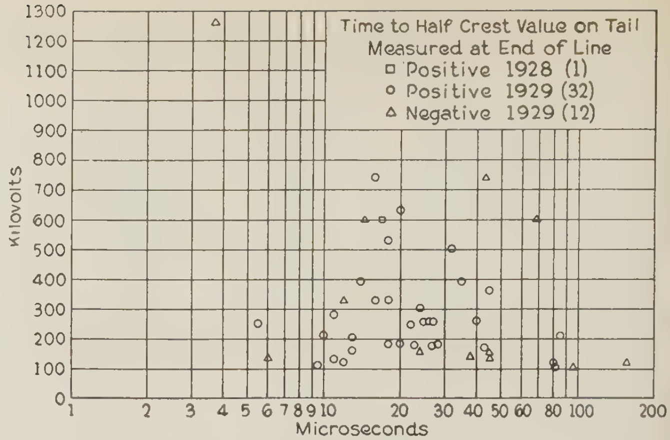

Fig. 2. Time of half crest value on tail of the 45 waves whose lengths of front are shown in Fig. 1

sive. In this period it was possible to locate the flashovers fairly accurately. For the overhead ground wire section the ratio of flashed to total towers is about 1 in 10; for the section without overhead ground wires the ratio is about 9 in 10. For the overhead ground wire section there were no flashed towers where the grounding resistance is 12 ohms or less, regardless of the manner of grounding. For the section without overhead ground wires the tower footing resistance apparently is immaterial. This may be because in this section many of the strokes are direct to the conductor; for such strokes tower footing resistance has no effect on flashover.

From the data here presented, it is evident that the overhead ground wire is effective in preventing line flashover, that it is more effective the lower the tower footing resistance, and that this particular line is immune from flashover if the tower footing resistance is 12 ohms or less.

Calculations have been made for the location of overhead ground wires to take care of direct strokes.[6] These calculations are based upon assumptions as to the lightning potential at the instant of contact with the overhead ground wire, such assumed values varying from 5,000 to 20,000 kv, and also upon assumptions as to the steepness of wave front of the lightning stroke. These values have not been substantiated by measurements of stroke potential and wave front at or near the point of contact of the stroke. The recommended height of ground wires above conductors varies from 20 to 50 ft, depending upon the assumptions.

It is useful to review the data secured by the cathode ray oscillograph concerning length of front and duration of waves on transmission lines; this will be done in a later section. It is useful also to review the ground wire arrangements now in use on practical lines and to see how these lines have operated.

In Table VII are listed several 220-kv lines in Pennsylvania, New Jersey, and Maryland, also a 66-kv line in Pennsylvania and 110- and 132-kv lines in New York. Data are given as to the line insulation, distance between conductors, distance between ground wires, and height of ground wires above conductors, also as to the number of tripouts and tripouts per 100 miles of line per year. It is not apparent from this tabulation that line construction or location of overhead ground wires accounts for the difference in performance of these lines. It is probable that 2 factors missing from the tabulation, namely, tower footing resistance and storm severity, together with line insulation, are the important factors that account for most of the differences in line operation.

Length of Wave Front and Duration of Waves on Transmission Lines

During the years 1928 and 1929 a laboratory with cathode ray oscillographs was located within 300 ft of the Wallenpaupack Station of the Wallenpaupack-Siegfried line, and in 1930 the laboratory was located at Cherry Valley, about 42 miles south of Wallenpaupack. In Fig. 1 are plotted the wave front (time from beginning to crest) against kilovolts for 45 waves of which cathode ray oscillograms were secured at Wallenpaupack in 1928 and 1929, and in Fig. 2 are plotted the time to half crest value on the tail (measured from the beginning) against kilovolts for the same waves.

In Fig. 3 are plotted the wave fronts against kilovolts for 16 waves the oscillograms of which were secured at Cherry Valley in 1930, and in Fig. 4 the time to half crest value on the tail against kilovolts for the same 16 waves. One oscillogram (Fig. 5) taken at Cherry Valley is not plotted. This was a direct stroke that flashed over the line insulators at approximately 3,000 kv on the front of the wave; therefore, this wave could not be included on the same basis as the others.

These figures show that in general the waves at the mid-point of the line are shorter, both as to front and duration, than the waves at the end of the line. Possibly the difference in length may be accounted for by the waves being recorded nearer their origin at Cherry Valley than at Wallenpaupack. The waves recorded at the latter place would tend to attenuate and lengthen out both on the front and tail by travel over the transmission line. At the end of the line the waves may reflect and increase in voltage; this increased voltage would tend to arc

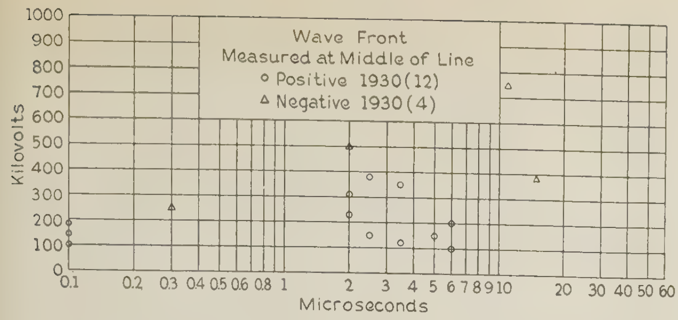

Fig. 3. Length of front of 16 waves caused by lightning on the 220-kv Wallenpaupack-Siegfried line as recorded at midpoint of line by cathode ray oscillograph

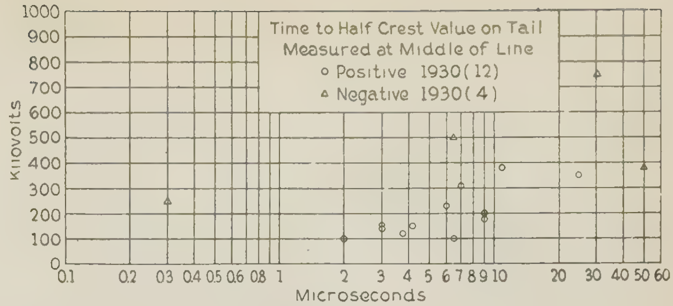

Fig. 4. Time of half crest value on tail of the 16 waves whose lengths of front are shown in Fig. 3

over the oscillograph trip-gap oftener, thus giving more records.

Mechanism of Flashover

Many helpful studies of lightning tripouts of transmission lines have been made in an effort to reduce the problem to one of engineering calculation. However, inasmuch as great uncertainty has existed regarding the actual electrical mechanism of the lightning stroke and the manner in which it builds up flashover voltage across insulators after striking the line, most of these studies have been based upon assumptions which have made conclusions questionable.

Somewhat in disagreement with the usual conception of the stroke as a traveling wave advancing from the cloud to the line, it has been pointed out that the stroke actually begins at the line and advances upward toward the cloud.[7] Considerable laboratory and field experience appear to substantiate the latter viewpoint. Recently a valuable photographic study of lightning[8] has resulted in the conclusion that after a downward leader or dart stroke provides an ionized pathway for the main discharge current, the main stroke follows immediately, passing upward from ground to cloud. The polarities found were cloud base negative and ground positive, which is in agreement with the surge crest ammeter findings given in this paper.

One cathode ray oscillogram of conductor potential was obtained for a direct stroke to the conductor[9] on the Wallenpaupack-Siegfried line. This section of line was without overhead ground wires and the stroke hit the conductor within a span (1,000 ft) of the oscillograph. The oscillogram shows a time from the beginning of the voltage rise on the conductor to flashover of about 5 μsec (Fig. 5). The conductor potential at the point of measurement built up slowly to 1,000,000 volts in about 4 μsec, then more rapidly to 3,000,000 volts at the end of 5 μsec. A velocity of propagation of the lightning stroke upward of approximately 150 ft per microsecond[8] would indicate that the main streamer had progressed less than 1,000 ft toward the cloud. The 3,000-kv conductor potential, assuming a surge impedance of 300 ohms, indicates a current of 10,000 amperes, which should be at least doubled to account for current flowing in both directions in the conductor. Assuming as indicated by crest current records that this stroke current was at least 60,000 amp, the total time element involved in the current wave front would be 8 or 10 μsec and the upward penetration of the main streamers would have reached approximately 1,500 ft in this time. The time required to reach the cloud would be at least 30 μsec assuming the cloud height to be about 4,500 ft. A total time for stroke duration might be about 100 μsec, during the last 70 of which the current dropped from 60,000 amp to zero.

In view of this order of current variation, and in connection with strokes to the tower structure, it is interesting to recognize that the tower and counterpoise are short in time length. With the lightning current rising slowly at first as the stroke proceeds upward, then more rapidly, but never at such a rate as to give important potential differences along the tower, counterpoise, or in the ground due to distance, the tower potential can rise to insulator flashover levels only by virtue of resistance potential drop in the tower footing. Lightning stroke recorder readings of potential across 35 to 40 ft of vertical tower structure have had an upper limit of approximately 40,000 volts. This shows the impedance drop along the tower structure to be unimportant as regards flashover. The problem of limiting tower potentials therefore becomes one of limiting tower footing resistance. This is accomplished by reducing the high current densities at the immediate tower footing through the use of buried counterpoise wires which carry the current away from the tower structure.

This way of looking at the situation means that

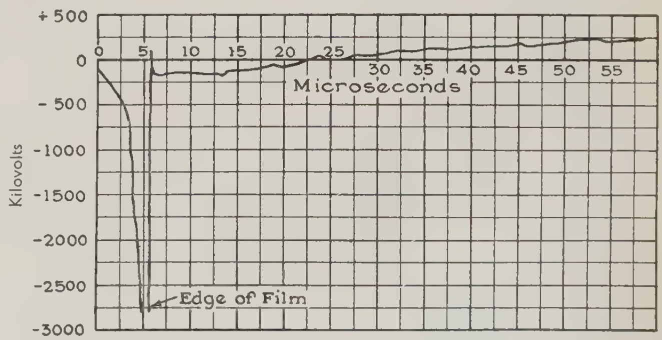

Fig. 5. Reproduction of oscillogram of a direct stroke at Cherry Valley laboratory, Wallenpaupack-Siegfried 220-kv line, July 24, 1930

the problem of reducing outages can be handled effectively merely as a problem of limiting the tower potentials on an ordinary resistance basis, rather than on the basis of dealing with a complexity of traveling wave reflections and couplings.[6,10] A solution obtained on this basis, together with the use of the overhead ground wire to prevent the stroke from beginning on the conductor, assures in most cases immunity from tripouts due to lightning.

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Analytical Representation of a Magnetizing Curve

A method of representing approximately an empirical magnetizing curve is outlined in this article. An example illustrating application of the method is included.

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Magnetic circuits of commercial electrical apparatus usually are more or less saturated at the normal operating voltages, and the magnetizing or saturation curves of such apparatus expressing the relationships between the magnetic flux and the magnetizing current can be represented only by empirical curves that are obtained point by point either from design calculations or from test data. As a consequence, in several instances the solution of equations expressing certain characteristics of electrical apparatus and containing terms representing the flux cannot be found analytically, because it is not possible to eliminate the flux terms from such equations and introduce instead terms designating the magnetizing current. In such cases methods of graphical solution must be resorted to.

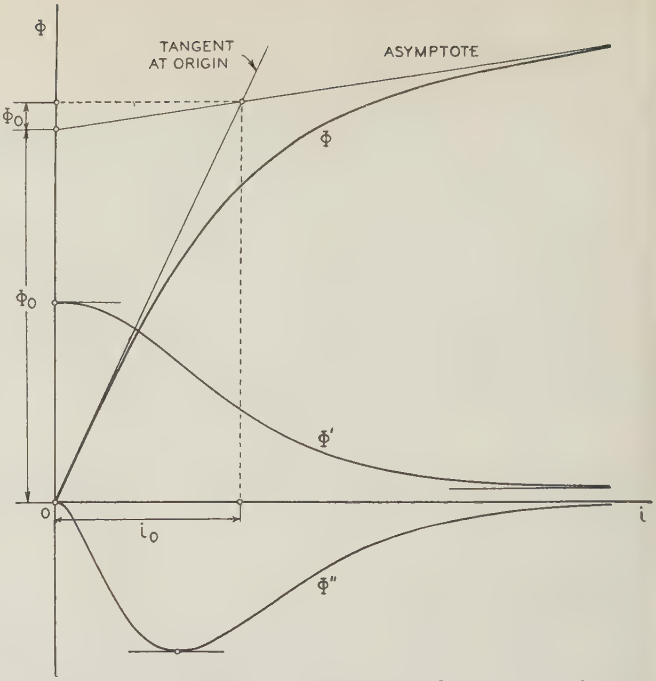

Fig. 1. Magnetizing curve, $\Phi = f(i)$, its first derivative, $\Phi' = f'(i)$, and its second derivative, $\Phi = f''(i)$. The tangent at the origin and the asymptote of the curve determine the constants i_o, Φ_o, and k, as indicated

If, however, an investigation involving magnetic saturation is of a more or less general character, it appears desirable to indicate the general equation of an analytical curve containing one or more parameters; to these parameters such values must be attributed as to make the analytical curve represent with reasonable accuracy the empirical magnetizing curve of an electric apparatus, because such an equation makes it possible to eliminate the flux terms from the equations previously referred to. A method of representing approximately an empirical magnetizing curve (for instance, the saturation curve of a d-c generator) is outlined in this article.

When a magnetizing curve the equation for which is $\Phi = f(i)$, and curves for the first derivative $\Phi' = f'(i)$ and the second derivative $\Phi'' = f''(i)$ are examined (see Fig. 1) it becomes evident that it should be possible to approximate the (negative) ordinates of the Φ'' curve by a product of 2 factors; the first of these factors is proportional to the square of the abscissa, and the second to a power of ϵ (the base of Naperian logarithms) containing in the exponent the abscissa with negative sign. It should

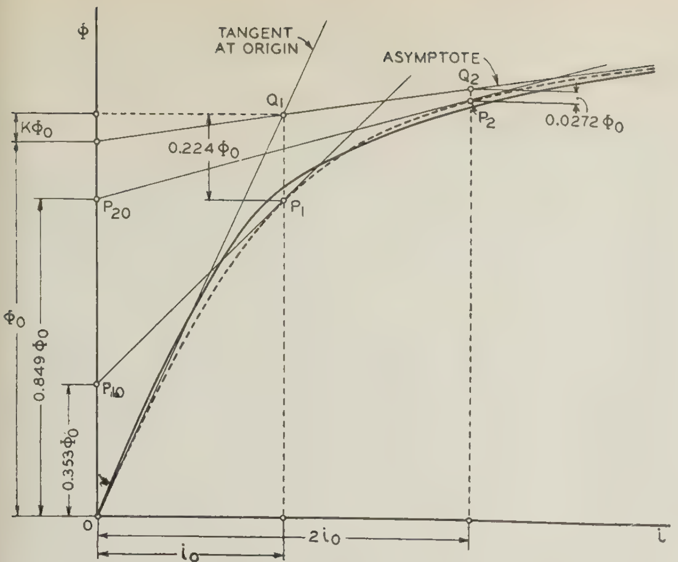

Fig. 2. Empirical magnetizing curve (solid line curve) and its analytical approximation (dotted line curve)

be possible, therefore, to adopt for the Φ'' curve the equation:

$$\Phi'' = -ai^2 \cdot \epsilon^{-\frac{i}{b}} \tag{1}$$

in which a and b are 2 positive constants (parameters). Like the empirical Φ'' curve, the curve representing this equation has a minimum for a positive value of i, whereas the axis of abscissas is both a tangent at the origin and an asymptote of the curve. The adoption of the equation just given offers certain advantages from a mathematical standpoint, because, in general, any function $i^n \epsilon c^i$ can be integrated readily for all integral values of n, although a series representation of the integral function is necessary when $n = -1$.

The equation for Φ is obtained from eq 1 by integrating twice; consequently, the equation for Φ will contain, in addition to the 2 parameters a and b, 2 constants of integration, that is, a total of 4 constants. These 4 constants can be determined by imposing the conditions that the analytical Φ curve must pass through the origin O, and must have the same tangent at the origin and the same asymptote as the empirical magnetizing curve. The data (i_0, Φ_0, and $k\Phi_0$) determining this tangent and this asymptote are indicated in Fig. 1.

The result of twice integrating eq 1, and of introducing the proper values for the 4 constants in line with the foregoing, will not be given in the form $\Phi = f(i)$, because it is more advantageous to introduce the ratios:

$$x = \frac{i}{i_0} \qquad y = \frac{\Phi}{\Phi_0}$$

in which case (provided that x is positive) the *characteristic equation of the magnetizing curve* appears in the form:

$$y = kx + 1 - \left(\frac{3}{2}x^2 + 2x + 1\right) \cdot \epsilon^{-3x} \tag{2}$$

This equation contains only one parameter, k.

Example

An example, showing how this method of approximating a given magnetizing curve by means of an analytical curve as per eq 2 should be applied in a concrete case, is given in Fig. 2. First, the tangent at the origin and the asymptote for the given curve must be drawn; second, i_0, Φ_0, and $k\Phi_0$ must be determined from the diagram thus obtained, so that the magnitudes of i_0, Φ, and k become known (in Fig. 2, $k = 0.075$). Equation 2 then gives y as a known function of x, and, as a consequence, Φ becomes a known function of i.

In Fig. 2, the empirical (given) curve is indicated by a heavy line and its analytical approximation by a dotted line, thus clearly revealing the discrepancies between the 2 curves. By slightly varying the inclinations of tangent and asymptote (these 2 lines cannot be drawn with absolute accuracy anyway) an equation (2) can be found for which these discrepancies will remain within reasonable limits. In order to obtain some idea about the degree of approximation, the analytical curve should be plotted so that it can be compared with the empirical curve; it should be emphasized, however, that not many points of the analytical curve need to be calculated for this purpose. In general, it will be sufficient to determine, in addition to the tangent at the origin and the asymptote which can be considered as given, 2 points of the analytical curve and the tangents at these points. For instance, the points P_1 and P_2 (see Fig. 2) with abscissas i_0 and $2i_0$, can be chosen for this purpose; for any value of k, the locations of these points are determined by:

$$Q_1P_1 = 0.224\ \Phi_0 \qquad \text{and} \qquad Q_2P_2 = 0.0272\ \Phi_0$$

whereas the tangents $P_{10}P_1$ and $P_{20}P_2$ are determined by:

$$OP_{10} = 0.353\ \Phi_0 \qquad \text{and} \qquad OP_{20} = 0.849\ \Phi_0$$

(These relations can be derived easily from eq 2.) This means that, when applying the method and after drawing the tangent at the origin and the asymptote, the points P_1 and P_2 can be located directly, the tangents $P_{10}P_1$ and $P_{20}P_2$ drawn, and the analytical curve traced.

When problems involving a reversal of field (magnetizing) current must be dealt with, it should be remembered that eq 2 applies only for positive values of x; for negative values of x (negative branch of the magnetizing curve) the following characteristic equation must be used instead:

$$y = kx - 1 + \left(\frac{3}{2}x^2 - 2x + 1\right) \cdot \epsilon^{+3x}$$

When the residual magnetism of apparatus must be taken into account (for instance, in problems dealing with self-excited d-c generators) eq 2 can be used without modification, provided that in Fig. 1 the portion of the axis of ordinates now designated by $k\Phi_0$ is put equal to $k(\Phi_0 - \Phi_r)$ and that, instead of the ratio $y = \dfrac{\Phi}{\Phi_0}$, the ratio $y = \dfrac{\Phi - \Phi_r}{\Phi_0 - \Phi_r}$ is introduced, where Φ_r designates the residual flux of the apparatus.

Lightning Investigation on a 220-Kv System

Investigation of the effects of lightning discharges on the 220-kv transmission lines of the Pennsylvania Power and Light Company has been continued over a period of several years; results obtained during the period 1931–33 are reported and analyzed in this paper. By the use of the "distribution ratio method" of locating faults nearly all 220-kv faults causing line tripouts were found quickly and positively correlated with time, dynamic current, lightning current, insulator flashovers, line construction, and tower footing resistance.

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LIGHTNING RESEARCH has been conducted on the Pennsylvania-New Jersey 220-kv interconnection for the past several years for the purpose of obtaining knowledge of the magnitude of lightning, and of its distribution and effects on high voltage transmission lines of various types of construction; also to investigate the effects of low tower footing resistance and special grounding devices such as continuous counterpoise and tower footing grounding cables. This paper briefly describes the research conducted during 1931–33 by the Pennsylvania Power and Light Company with the coöperation and assistance of the General Electric Company and the Electric Bond and Share Company, which was confined largely to the former Wallenpaupack-Siegfried 220-kv line; the paper includes also line tripout and flashover data from all 220-kv lines of the interconnection.

Research conducted up to and including 1930 has been reported previously.[1, 2, 3] During the period 1931–33, this work has consisted chiefly of the acquisition and study of operating records (flashovers, tripouts, and magnetic oscillograms of fault currents), line betterment (performance of counterpoise, etc.), and field research (lightning strokes and lightning severity). Plentiful results of diverse nature have been obtained, including records of lightning strokes, structure current magnitude and polarity, number and locations of insulator flashovers, effect of tower footing resistance and various tower grounding devices, lightning storm severity records, and so on. A technique has been perfected whereby locations of dynamic arcs can be estimated within a few miles, using graphic ammeter records. This unique method has permitted nearly all 220-kv faults causing line tripout to be found quickly and positively correlated with time, dynamic current, lightning current, insulator flashover, line construction, and tower footing resistance. Correlated data of these kinds have yielded valuable insight into the mechanism of lightning faulting of highly insulated transmission lines and demonstrate the effectiveness of low tower footing resistance when overhead ground wires are present.

As far as the circuits of the Pennsylvania-New Jersey 220-kv interconnection are concerned, the following conclusions seem justified:

1. Conventional overhead ground wires provide protection against most of the direct strokes encountered.

2. Most lightning tripouts result from single-phase-to-ground faults.

3. Insulator flashovers causing line tripouts usually involve but one phase. When overhead ground wires are present, the majority of flashovers occur on one structure only, and when absent, the majority of flashovers involve several adjacent structures (usually 2).

4. Records of structure current resulting from lightning are practically all of negative polarity. Magnitudes as great as 41,000 amperes have been registered.

5. Tower footing resistances of less than 13 ohms appear to enable the overhead ground wires of the Wallenpaupack-Siegfried line to protect the line against all strokes of lightning. This tentative value of resistance appears to be independent of special tower footing grounding cables and counterpoise.

Description of Line

Although a description of the former Wallenpaupack-Siegfried line has been given elsewhere, it is believed worth while to present here a brief review of its design, history, and present status. The circuit comprising the former Wallenpaupack-Siegfried line is 65 miles long and of steel-tower, single-circuit, horizontal-configuration design. Conductors are 795,000-cir-mil A.C.S.R. (aluminum conductor steel reinforced), are spaced 22 ft $7^1/_2$ in. apart, and are supported by 16 (or 14) insulator units spaced $5^3/_4$ in. Two overhead ground wires of 184,000-cir-mil A.C.S.R. spaced 22 ft 7 in. apart and about 10 ft 6 in. to 11 ft 6 in. above the line conductors, were installed over 37 per cent of the line after $1^1/_2$ years of operation. Two sections, one about $19^1/_2$ miles long and extending south from Wallenpaupack, and one about $4^1/_2$ miles north from Siegfried, were so equipped. Flashovers still occurred on these sections of line, especially over High Knob (a rocky prominence 12 miles south of Wallenpaupack); consequently, early during 1929 a counterpoise consisting of a single continuous 2/0 copper cable was installed for a distance of 2.6 miles over this ridge. It was bonded to 2 footings of each of the 14 towers which it connected, was trenched in the earth and loose rock where this was possible and terminated at either end in a network of driven rods. Tower foot-

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1. For all numbered references see list at end of paper.

ing resistances which formerly varied from 50 to 150 ohms were reduced to about 1 to 1.5 ohms.

During 1930 the remaining $16^1/_2$ miles of overhead ground wire section near Wallenpaupack, and during 1931 the $4^1/_2$-mile section near Siegfried, were equipped with a less costly though less effective means of tower footing groundings. Groups of 4 buried 50-ft cables, perpendicular to each other and extending radially outward at 45 deg to the direction of the line were installed, each cable being bonded to its tower footing. These installations did not produce the extremely low resistance of the counterpoise, but effected reductions of about 50 per cent over former values. New resistances range from 3 to 85 ohms, with an average of 32 ohms.

During 1930 special overhead ground wires of 180,000-cir-mil A.C.S.R. were installed over a $3^1/_2$-mile section of line about 21 to $24^1/_2$ miles south of Wallenpaupack. These lightning stroke diverting[4] cables are supported on wood poles about 35 ft above the tower bridge, and anchored to earth by 4 (or 6) "copperweld" steel guys per structure. The 2 overhead cables are cross-bonded at each structure and are insulated from the tower tops by the long wood poles; they are grounded by means of the guys and are bonded to the tower footings through buried return cables similar to the tower footing grounding cables, but necessarily much longer.

During April 1932, a 220-kv tie[5] from Bushkill, Pa., to Roseland, N. J., was placed in service forming a Y-shaped line having terminals at Wallenpaupack, Siegfried, and Roseland and lengths of 28, 37, and 46 miles, respectively. The latter (new) section is completely covered by 2 overhead ground wires.

The circuit comprising the former Wallenpaupack-Siegfried line extends from Wallenpaupack, Pa., through Bushkill to Siegfried, Pa. The 83-mile circuit from Siegfried to Roseland is now called the Siegfried-Roseland line, and the 28-mile circuit from Wallenpaupack to Bushkill is called the Wallenpaupack tap. Since in general the research still has been conducted on the circuits comprising the former Wallenpaupack-Siegfried line, they accordingly will be designated by that name in this paper.

Field Research Methods and Devices

Records of line tripouts, insulator flashovers, and magnetic oscillograms have been kept regularly as well as field records from specialized devices, particularly on the former Wallenpaupack-Siegfried line. The *surge indicators*[6] installed on that line during 1930 have proved valuable in locating flashovers. These devices, one of which is coupled to each insulator assembly, are operated by surge current in the tower bridge, particularly that flowing over an insulator assembly when flashed by lightning. After operation, a yellow semaphore target is exposed and can be seen by a patrolman on the ground.

During 1929, a partial installation of *lightning stroke recorders*[7] was made. These instruments, which are inherently voltage-measuring devices utilizing Lichtenberg figures on camera film, record the polarity and approximate crest voltage of surges. They are used to measure the voltage drop across a section of tower when lightning current flows through the structure. The few installations of this device in 1929 spanned about 30 to 35 ft on the outside of one tower leg only, instead of reaching from the bottom of one leg to the top of the diagonally opposite leg as in certain other investigations. During 1930 each of the 314 line structures was equipped, and later during that season the installations were improved by substituting a longer and more rigid lead. During 1931 improved moisture-proof film packets of increased sensitivity replaced the former paper packets, and have been used each year since. During the 4-yr period 1930–33, 352 records have been secured.

During 1932, a different device, utilizing laminated steel links of high retentivity which are magnetized by the field surrounding a current carrying conductor, and designed to measure the polarity and crest magnitude of nonoscillatory structure currents, was proposed; 33 of these devices were installed. These *surge crest ammeters*,[8] as they are called, yielded no records, probably because of insufficient sensitivity. During 1933, all 314 towers were equipped with devices of improved design and about double the former sensitivity; 32 records were obtained.

During 1930, the *lightning severity meter*[6] was first tried in a limited way. This is a small integrating camera-like device, containing a gaseous glow tube connected in series between a 30-ft vertical antenna and ground. Electrostatic charges which collect upon the antenna (such as those from charged clouds) are discharged suddenly through the tube when the surrounding atmospheric field suffers a reduction in intensity from a lightning discharge in the vicinity. Successive discharges cause a cumulative darkening of the stationary film, which is left exposed for a period of one week.

Because the lightning severity meter records a phenomenon that is affected by conditions within a somewhat extensive area, is cumulative in action, and records all disturbances great and small over a weekly period, its story cannot be correlated satisfactorily with specific occurrences such as known lightning strokes, insulator flashovers, etc. It seems to possess merit as a "lightning survey" meter in selecting between alternative routes for future transmission lines.

Results—General

It is not possible to present in detail all data secured since 1930. The plan used includes summaries of data obtained during these and prior years, specific detailed samples, and statistical tables. Valuable insight into the mechanism and results of lightning influence on this line has been obtained from correlated data of different kinds, all relating to a single series of occurrences, and the use of these facilities has reduced the amount of line patrolling formerly necessary after storms. For example, assume a given storm causing 2 line tripouts. Associated in time with the relay and oil switch operations are magnetic oscillograms and graphic ammeter records, and dynamic arcs somewhere on the line. The approximate location of these arcs is estimated[11] from recorded values of line residual or transformer

bank neutral currents, and the phase or phases involved are determined from the same oscillograms. Consequently, patrolling usually is necessary only within about 5 miles each way from each estimated location, to permit discovery of the surge indicator operations and flashed insulators, and collection of lightning stroke recorder film packets and magnet links. Complete line patrols and changes of all film packets and magnet links are made at intervals of 2 months. Table I presents typical information secured concerning a line tripout.

Correlated information has permitted determination of the locations of 72 tripouts on the Wallenpaupack-Siegfried line. Since 1930, all but 2 of the 45 tripouts have thus been located. Prior to and including 1930, when technique was less developed, 29 out of 98 tripouts definitely were identified.

Lightning Severity; Lightning Stroke Records

Results obtained with the lightning severity meter have been reported in terms of "index numbers" and also "charge numbers." An index number is the $\log_2$ of the corresponding charge number. The latter represents the total charges summed up over the period of a week. Both numbers have been used as a means of comparing lightning severity at different sites. Table II lists season averages of index numbers and charge numbers for the past 3 years from 11 sites in Pennsylvania, the last 4 being adjacent to, or near the terminals of, the former Wallenpaupack-Siegfried line.

Typical weekly records for the 1933 season from sites 1, 7, and 9 representing severe, moderate, and mild exposures, are shown as Fig. 1.

Most of the lightning stroke records from this line have been obtained from the lightning stroke recorder, which apparently is quite sensitive to voltage disturbances. Besides recording most of the direct strokes to the tower to which the recorder is coupled, the instrument is affected by other disturbances which perhaps result from strokes to nearby objects and/or induced strokes. The records cannot always

Table I—Representative Line Tripout Data—Former Wallenpaupack-Siegfried Line

Date and time	June 3, 1933, 4:55 p.m.	
Line name and tripout no.	Siegfried-Roseland No. 5	
Phase or phases involved	Y (single phase to ground)	
Initial residual amperes and breaker operating times — Wallenpaupack	320 amp., 121 cycles	
— Siegfried	1,740 amp., 29 cycles	
— Roseland	430 amp., 81 cycles	
Estimated fault location	about 7.2 miles north of Siegfried	
Towers affected	SR 7-1	SR 7-2
Flashed insulators	Yes	Yes (1 unit broken)
Did surge indicators work?	Yes	Yes
Lightning stroke recorder polarity	Negative	Negative
Surge crest amperes	—Trace	—12,000
Overhead ground wires	No	No
Tower footing resistance, ohms	17	12

Table II—Lightning Severity at Typical Sites

		Season Averages					
		Index Numbers			Charge Numbers		
Site No.	Location	1931	1932	1933	1931	1932	1933
1	Jordan Valley	7.0	4.6	7.1	138	24	138
2	Blue Mountain Summit	4.7	3.4		26	11	
3	Lizard Creek Valley	5.0	3.2	5.5	32	9	45
4	South Tamaqua	7.6	6.2	8.2	195	74	295
5	Locust Mountain	5.7	3.9		52	15	
6	Broad Mountain	5.4	3.2	2.6	42	9	6
7	Frackville	4.6	3.6	4.9	24	12	30
8	High Knob Summit	6.1	6.5		69	91	
9	Cherry Valley	1.2	0.6	2.5	2	2	6
28	Siegfried			2.7			28
29	Wallenpaupack			3.1			31

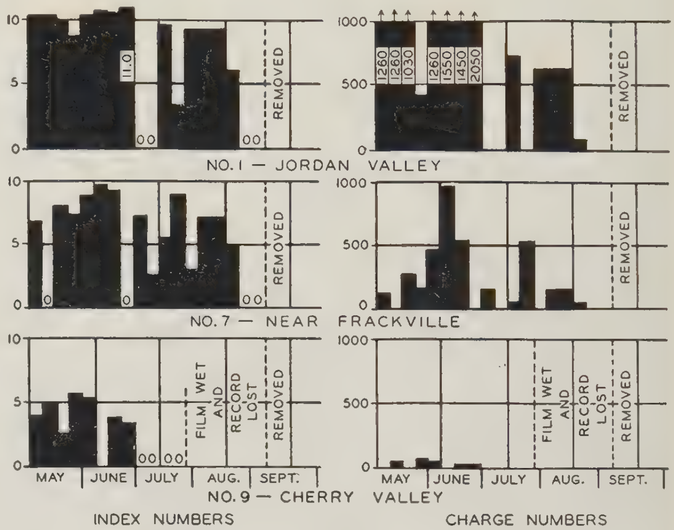

Fig. 1. Typical weekly records of lightning severity data obtained at 3 sites during 1933

These records, from top to bottom, are representative of those obtained at sites of severe, moderate, and mild exposure to lightning

Table IV—Comparison of Corresponding Registrations From Lightning Stroke Recorders and Surge Crest Ammeters

Device	Negative	Positive	Others	Total	% Negative
Lightning stroke recorder	25	2	3	30	83–93
Surge crest ammeter	29	1	0	30	96

Table III—Lightning Stroke Recorder Registrations on the Wallenpaupack-Siegfried Line

	Total Recorder Registrations					Apparent Strokes*				
Polarity	1930**	1931	1932	1933	Total	1930**	1931	1932	1933	Total
Negative	26	85	48	58	217	16	30	11	25	82
Positive	0	16	31	26	73	0	0	1	0	1
Others***	3	19	19	21	62	2	2	6	2	12

* In classifying records into "strokes," other data also have been used, such as insulator flashovers, surge (flashover) indicator operations, etc.
** The 1930 records were obtained from now obsolete, rather insensitive, paper film packets.
*** Many of these records have been classed as oscillatory, but they may have been caused by 2 or more successive and/or nonassociated disturbances. Some recorde are too small for polarity interpretation.

Table V—Correlated Lightning Surge Data for Former Wallenpaupack-Siegfried Line

Item No.	Line Name	Tower No.	Footing Resistance, Ohms	Surge Crest Ammeter Readings, Amperes	Products IR × 10⁻³ (See Note)	Overhead Ground Wires	Flashed Insulators and Phases	Trip-out No.	Lightning Surge Recorder Record
1	WT	4-5	26	−10,000	260	Yes	No	None	Neg.
2	WT	8-4	8	−23,000	184	Yes	No	None	Neg.
3	WT	8-5	7	−27,000	189	Yes	No	None	Neg.
4	WT	12-4	1	− 8,000	8	Yes†	No	None	Neg.
5	SR	2-1	15	−24,000	360	Yes	SI	None	Neg.
6	SR	2-4	10	−22,000	220	Yes	No	None	+ and −
7	SR	2-5	5	−10,000	50	Yes	No	None	Neg.
8	SR	4-2	8	−trace*	32	Yes	No	None	Neg.
9	SR	4-3	19	−trace*	76	Yes	No	None	Neg.
10	SR	4-4	19	−19,000	360	Yes	No	None	+ and −
11	WT	{27-6	58	−36,000	2,088	No	Yes, 1	15	Neg.
12	WT	28-1}	45	−trace*	180	No	Yes, 1	15	Neg.
13	WT	28-4	19	−12,000	228	Yes**	Yes, 1	14	None
14	SR	{7-1	17	−trace*	68	No	Yes, 1	5	Neg.
15	SR	7-2}	12	−12,000	144	No	Yes, 1	5	Neg.
16	SR	{8-1	34	−12,000	408	No	Yes, 1	7	Neg
17	SR	8-2}	23	− 8,000	184	No	Yes, 1	7	Neg.
18	SR	9-3	28	−10,000	280	No	Yes, 1	9	Neg.
19	SR	19-3	45	−26,000	1,170	No	Yes, 3	‡	Neg.
	SR	{24-1	48	None	None	No	Yes, 1	10	Neg.
20	SR	24-2}	20	−12,000	240	No	Yes, 1	10	None
21	SR	27-4	11	− 5,000	55	No	Yes, 1	17	Neg.
22	SR	31-3	34	−41,000	1,390	No	Yes, 3	‡	Neg.
23	SR	7-4	19	−trace*	76	No	No	None	Neg.
24	SR	8-4	20	−33,000	660	No	No	None	Neg.
25	SR	9-2	15	−12,000	180	No	No	None	Neg.
26	SR	20-1	30	−trace*	120	No	No	None	Neg.
27	SR	21-2	20	−30,000	600	No	SI	None	Neg.
28	SR	26-2	20	+trace*	80	No	No	None	Neg.
29	SR	27-3	15	−trace*	60	No	No	None	?
30	SR	31-4	14	− 8,000	112	No	SI	None	Neg.
31	SR	32-2	13	−12,000	156	No	No	None	Pos.
32	SR	32-3	27	− 4,000	108	No	No	None	Pos.

* A trace corresponds to about 4,000 amps. ** Stroke probably occurred to open line between towers WT 28-3 and 28-4. † Counterpoise installed.
‡ One of these flashovers caused tripout No. 11. No estimate of location could be made because of a lack of residual current.
WT—Wallenpaupack tap; SR—Siegfried-Roseland line; see text, "Description of Line."
SI—Indicates surge indicator operation but no flashed insulators.
Note: IR × 10^{-3} is the product of columns 4 and 5 divided by 1,000, and represents apparent kilovolts across the tower footing resistance. Flashover can occur (a) when the line conductor is struck, and (b) when the tower or overhead ground wire is struck and the product IR × 10^{-3} combined with the impedance drop (in kilovolts) through the tower structure exceeds the flashover strength of the line insulation, or between 1,400 and 2,200 kv. In case (a) flashover occurs from line conductor to tower and in (b) from tower top to line conductor. Items 13–18 and 20–21 apparently are examples of case (a) and items 11, 12, 19, and 22 of case (b).

be classified positively as having been caused by direct strokes although a judicious classification yields results probably not far from the truth. During 1933, some additional information was obtained from the surge crest ammeter.

To present in detail the large amount of data obtained is obviously impracticable. In general, records obtained since 1930 are similar though more numerous than those shown in Table V of the 1930 paper.[3] Existing records are summarized in Table III.

Corresponding to the 105 lightning stroke records obtained during 1933, there were 32 surge crest ammeter records. One reason for this small number of records is that the lightning stroke recorder responds to influences other than impedance drop resulting from direct strokes, whereas the surge crest ammeter is affected only by current. Another factor is that the latter devices were not in service as long as the former, nor were they serviced as frequently. Of the 32 records obtained, 30 have been correlated with lightning stroke recorder registrations. The remaining 2 records are associated with lightning strokes that yielded no lightning stroke recorder records. This peculiar characteristic of Lichtenberg figure cameras occasionally failing to yield a record[9] has been observed for some years though the reason is not known. In these 2 cases, insulators were flashed and line tripouts occurred. Surge crest ammeters in each case yielded records of 12,000 amp, negative. Table IV shows the excellent correlation between polarity of records from the 2 devices.

Surge crest ammeter records from the Wallenpaupack-Siegfried line have ranged in value from a trace (about 4,000 amp) to 41,000 amp. (Records of currents as great as 63,200 amp[10] have been obtained from the Glenlyn-Roanoke, Va., 132-kv line of the American Gas and Electric Company.) Table V presents detailed data and correlating information.

Counterpoise and Tower Grounding Cables

It has been mentioned that the counterpoise has effected an enormous reduction in tower footing resistance, and that about 50 per cent reductions have been obtained with tower footing grounding cables. Of more importance is the fact that no flashovers have occurred on the counterpoise section of line since the counterpoise cables were installed. Lightning severity data from High Knob previously shown indicates greater than usual lightning severity in that region. Prior to the installation of the counterpoise, 13 towers had been flashed over in that short 2.6-mile section. At least 2 of these occurred after overhead ground wires were in use.

The record of the tower footing grounding cables is not quite as good. Four towers have been flashed, resulting in at least one tripout. Nevertheless, the performance appears to have been improved, as Table VI shows.

Line Insulator Flashovers

Table VII lists the numbers of towers on which insulator flashover has occurred; these are designated as flashed towers. Usually, the flashover involved but one phase to ground. This compilation shows that from 85 to 95 per cent of all flashovers have occurred on the open sections of line and that on a comparable mileage basis, only about 11 per cent as many towers have been flashed on the sections protected by overhead ground wires as on open line.

Table VIII compares the numbers of flashed towers with the numbers of flashed insulator assemblies and surge indicator operations, and indicates that most flashovers involve only one phase.

Table VI—Results of Wallenpaupack-Siegfried Line Betterment

Line Section	Miles	Years	No. Towers Flashed	No. Line Trip-outs	Flashed Towers** per 100 Circuit Miles per Year	Tripouts per 100 Circuit Miles per Year
Counterpoise (1929–33)	2.6	5	0	0	0	0
Diverting cables (1930–33)	3.7	4	0	0	0	0
Tower footing grounding cables (1930–33)	21*	4*	5†	2	4.8†	1.2‡
Standard overhead ground wires (1927–29)	22*	2.5*	12	3	20.0	5.5
Open line (1926–33)	43.8*	8*	228	87	65.0	24.8

* Approximate values.

** A flashed tower is that on which one or more insulator assemblies has flashed over, and which may have involved 1, 2, or 3 phases. If the same tower was reflashed later it has been counted as 2 towers, and so on.

† Only 4 of these 5 items can be charged to failure of the tower footing grounding cables, and the figure of 4.8 is on this basis. Tower footing resistances were 13, 15, 34, and 56 ohms.

‡ Only one of these 2 items can be charged to failure of these cables, and the figure of 1.2 is on this basis. The tower footing resistance was 13 ohms. Surge indicator operations occurred at this and 2 adjacent towers and lightning stroke records at this and the next tower.

Note: The extra flashed tower and line tripout is included in the open line data.

Line Tripouts

Table IX lists the numbers of tripouts that have occurred on the open and overhead ground wire sections of line, as well as those the locations of which could not be determined with certainty. Of the 143 tripouts listed, the exact location of the fault and the number of circuit phases involved are known in 72 cases. Table X shows the numbers of phases involved in these tripouts.

Records from other 220-kv lines equipped with overhead ground wires involving 18 more tripouts show that the proportional numbers of faults affecting 1, 2, and 3 phases are 68, 23, and 9 instead of 50, 25, and 25 as shown in Table X; this demonstrates that for horizontally configurated lines of these types single-phase faults are in the great majority.

Magnetic oscillograms have been invaluable in several respects. One use has been to facilitate estimating fault location[11] when the fault involved only 1 or 2 phases and residual currents were measured. Other uses have been to show the phase (or phases) involved in a flashover, changes in current magnitude and direction of power flow, times of relay and breaker operation, and the few cases where single-phase-to-ground arcs changed into 2-phase-to-ground arcs. Table XI shows the segregation of 90 tripouts on the 220-kv Pennsylvania-New Jersey interconnection (of which the numbers of phases involved and actual locations are known) into those involving 1, 2, or more adjacent structures.

It has been shown previously that most faults in

Table VII—Flashed Towers* on the Wallenpaupack-Siegfried Line

Construction	1926	1927	1928	1929	1930	1931	1932	1933	Total	Per Cent	No. per 100 Circuit Miles per Year
	Year										
Overhead ground wire**		0	4	4	5	1	2	1	17	5.0	9.3
Open line†	18	4	74	71	45	36	15	25	288	85.2	82.8
Unknown	0	11	22	0	0	0	0	0	33	9.8	

* Towers on which one or more insulator assemblies have been flashed. ** Average mileage, 6.5 years, 28.3. † Average mileage, 8 years, 43.5.

Table VIII—Flashed Towers and Insulator Assemblies, and Surge Indicator Operations on the Wallenpaupack-Siegfried Line

	1926	1927	1928	1929	1930	1931	1932	1933	Total
	Year								
Flashed towers	18	15	100	75	50*	37	17	26	338**
Flashed insulator assemblies	24	25	128	90	56*	38	22	34	417**
Surge indicator operations					38*	56	42	56	192**

* 29 flashed towers and 34 flashed assemblies correlate with the 38 surge (flashover) indicator operations.

** 109 flashed towers and 128 flashed assemblies correlate with the 192 surge (flashover) indicator operations.

Table IX—Tripouts on the Wallenpaupack-Siegfried Line

Construction	1926	1927	1928	1929	1930	1931	1932	1933	Total	Average per 100 Circuit Miles per Year
	Year									
Overhead ground wire		0	1	1	1	0	1	0	4	2.2
Open line	15	4	2	10	14	20	9	13	87	25.0
Unknown		3	11	27	9	0	0	2	52	

Table X—Phases Affected in Tripouts on the Wallenpaupack-Siegfried Line

No. of Faulted Phases	Overhead Ground Wire Section No.	%	Open Line Section No.	%	Total No.	%
1	2	50	55	81	57	79.2
2	1	25	7	10	8	11.1
3	1	25	6	9	7	9.7
Total	4	100	68*	100	72	100.0

* Although at least 87 open line tripouts have occurred, only 68 have been positively located.

Table XI—Phases and Towers Involved in 220-Kv Faults

		220-Kv Tripouts: Open Line Section Number	Per Cent	Overhead Ground Wire Section* Number	Per Cent
Single-phase faults	total	55	81	15	68
	involving 1 structure	20	29	12	54
	involving 2 structures	31	46	2	9
	more than 2 structures	4	6	1	5
Multiphase faults	total	13	19	7	32
	involving 1 structure	4	6	7	32
	more than 1 structure	9	13	0	
		68	100	22	100
		68	100	22	100

* Only 4 of these 22 tripouts occurred on the former Wallenpaupack-Siegfried line.

volve but one phase conductor. Table XI shows also that when overhead ground wires are present, most of the few faults involve but one structure; but when they are absent, most of the large number of faults involve 2 adjacent structures. The 22 tripouts on sections of line equipped with overhead ground wires occurred over a 6-yr period (1928–33) on 241 miles (average) of circuit, whereas the 68 tripouts on lines not so equipped occurred during the same 6-yr period on 38 miles (average) of circuit. Reduced to a more comparable basis, there were 29.8 tripouts (average) per 100 circuit miles per year on open line and only 1.5 on line equipped with ground wires.

Tower Footing Resistance

It would be very helpful if the secret of how much and why tower footing resistance affects the operation of transmission lines could be made clear. Results usually are masked by many other effects, such as insulation strength of line, clearances and configuration of ground wires, season lightning severity and variations between routes of different lines, whether or not the resistances were measured with overhead ground wires disconnected from and insulated from the tower under measurement, presence of special grounding networks such as a counterpoise, and other factors. Overhead ground wires alone reduce frequency of flashover very greatly and the reason for the few remaining flashovers becomes difficult of solution. Assuming that the overhead ground wire has intercepted a stroke and is attempting to conduct it to earth, the suggestion has been made that flashover results when the product of structure current and tower footing resistance exceeds the insulation strength of the line. The problem is not as simple as that, however. It is evident that complications are introduced by surge wave front, reflections from tower top and tower footing, tower and ground wire impedance, and other factors; further complications result because of uncertainty as to how much the tower footing resistance at the time of a stroke differs from the ordinary "meggered" value, and because of the small amount of structure current data available.

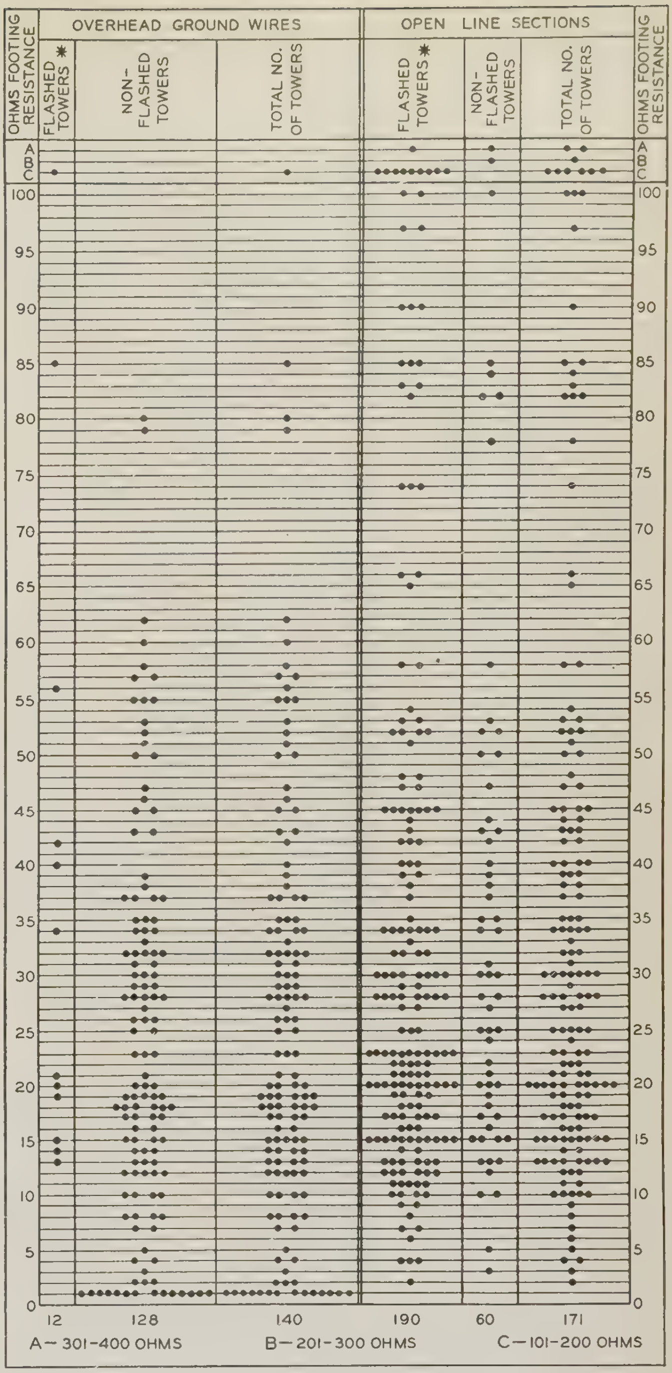

Fig. 2. Tower footing resistance and flashover data for the Wallenpaupack-Siegfried 220-kv line during the 5-year period 1929–33

*A flashover involving one or more phases of one tower is counted as one flashed tower; if reflashed later, it is recounted

Data on flashed insulators for 5 years have been employed to indicate the effect of tower footing

resistance on this line. Resistances were measured by megger with ground wires disconnected from the tower under test. Figure 2 is a tower footing resistance chart of the former Wallenpaupack-Siegfried line on which are represented by dots opposite the corresponding tower footing resistances, the total number of towers, the number of towers that as yet have not been flashed, and the number of towers on which flashovers have occurred. Towers that have been flashed 2 or more times are represented by a corresponding number of dots. The data in this form, although complete, do not give a clear insight into the effect of tower footing resistance; however, it can be seen that *few overhead ground wire structures have been flashed*, and that *few open line structures have not been flashed.* An inspection will reveal also that none of the 36 overhead ground wire structures having resistances less than 13 ohms ever have been flashed. Of the 19 such structures not equipped with overhead ground wires, 14 have been flashed, some several times, making a total of 25 flashovers.

A more complete idea of the effect of tower footing resistance can be obtained from Fig. 3. This chart, which is derived from the complete data of Fig. 2, is composed of dots each one of which represents 4 towers of approximately the same footing resistance, beginning with those of lowest value. The ordinate or height of a dot represents the number of flashed towers in that particular group. Since in this chart the "location factor" is fairly well averaged out, it is reasonable to conclude that in time each group of 4 towers will have been equally exposed to lightning, and differences in the number of flashovers that will have taken place will be a measure of the differences in the effectiveness of tower footing resistance in preventing flashovers.

Figures 2 and 3 represent 5 years' data. It may be seen that for the open line section, although random variations exist between different groups of 4 towers, there is no indication of any fundamental difference between towers of high and low resistances. All towers are equally vulnerable, which is to be expected, since tower footing resistance is not part of the lightning circuit until after flashover has taken place.

For the overhead ground wire section of line there are marked differences in vulnerability between groups of towers. Those having footing resistances of less than 13 ohms so far have been immune.

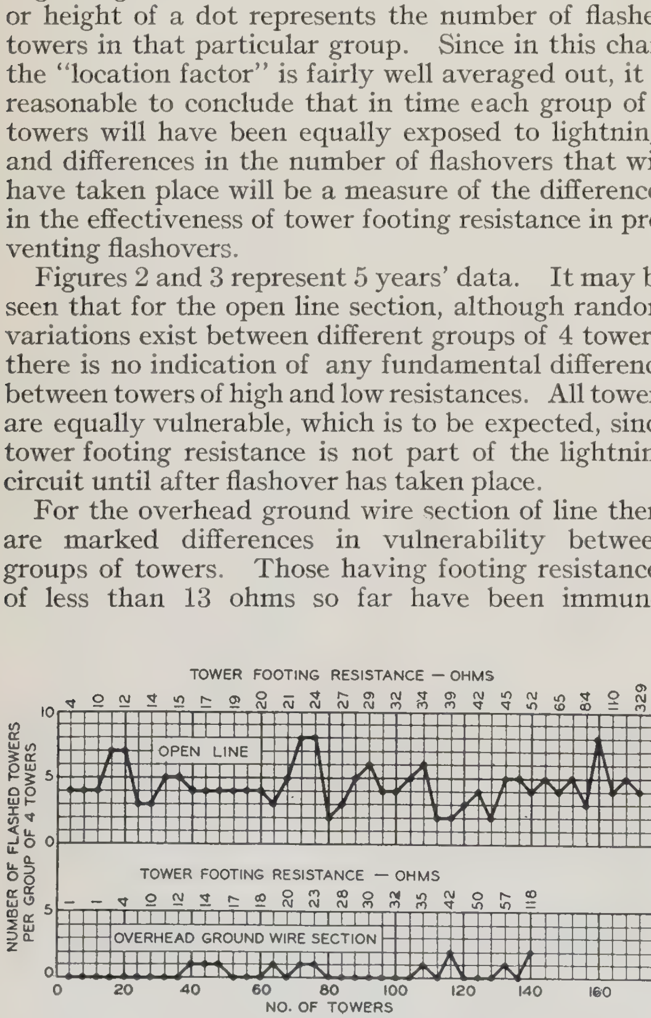

Fig. 3. Tower footing resistance and flashover data of Fig. 2 plotted in curve form; each dot represents 4 towers of approximately the same footing resistance

Those having resistances of more than 13 ohms are flashed occasionally although for resistances of less than 60 ohms not more than 1 tower in 4 is so characterized; between 60 and 118 ohms this number is increased to 2. The curve of these data shows that above 13 ohms there is a slight increase in vulnerability as resistances increase.

Similar data[12] from South Africa have been arranged by the writer into a chart similar to Fig. 3. These data show more clearly than the Wallenpaupack-Siegfried data the increased vulnerability of the higher resistance towers and the existence of a maximum safe value of tower footing resistance. For the Victoria Falls-Transvaal 132-kv lines, this value is 6 ohms, compared with 12 ohms for the Wallenpaupack-Siegfried 220-kv line. Between 7 and 24 ohms the maximum number of flashed towers per group of 5 towers is 1; above 24 ohms this number increases to 2 and ultimately to 3.

Figure 3 is presented not as a solution of the problem, but to stimulate more interest in the subject. It has been shown that of 2 lines of approximately similar construction and length, but having different average tower footing resistances, the one having the lower resistance will have a correspondingly better flashover and tripout record.[13] A study made by the writer on several pairs of lines of different voltage ratings and locations, suggests that the reason low resistance lines show improved performance is in the increased number of towers having resistances less than a "critical value" for the particular type of construction involved. Apparently for 3 pairs of medium voltage lines having one overhead ground wire, the critical resistances range in value from 2 to 7 ohms, whereas for a 230-kv line the value may be as great as 32 ohms; for the former Wallenpaupack-Siegfried line it appears to be about 12 ohms.

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Lightning Performance of 132-Kv Lines

Lightning performance of the 132-kv transmission lines of the American Gas and Electric Company during 1932–33 is reported in this paper. Analysis of lightning performance of these lines, records of which have been kept for the past 9 years, has resulted in definite progress being made in understanding the lightning problem and also in definite conclusions regarding many aspects thereof.

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Although the first 132-kv line on the present 132-kv network of the American Gas and Electric Company was placed in service in 1917, not until the lightning season of 1925 when 4 additional lines were in service did the importance of the lightning problem to the successful operation of such lines become apparent. The destructive effects on one of these lines that year already have been reported.[1] From that time on a careful record of the lightning performance of all lines on the 132-kv system has been kept yearly, studied, and correlated with pertinent features of the lightning protective problem as applied to transmission lines. Analyses of these records have been presented to the Institute in the past[2, 3, 4, 5, 6, 7] in the light of the knowledge, theory, and opinions on lightning prevalent at the time. It is the purpose of this paper to present and discuss the operating performance under lightning conditions during 1932 and 1933 of the lines of this 132-kv network which now comprise some 1,450 miles of tower lines.

Transmission System

The extent of the 132-kv network, country traversed, and type of construction, which have been described before,[5] were practically the same in 1932 and 1933 except that the single-circuit lines 8, 9, and 10 (Table III) were double-circuited during most of the 1933 lightning season. All the lines, except 60 miles of wood pole line, are of steel tower construction; all steel tower lines are equipped with 1 ground wire at the tower peak, and a few with 2 ground wires.

A general summary of the types of lines is given in Table I, the 60-cycle and impulse flashover voltages of the insulators in Table II, and more details concerning each line and their detailed operating performances in Table III.

Line Outages and Lightning Storm Data

Line outages for the various classifications of lines are given in Table IV, and have been plotted together with lightning frequency and severity in Figs. 1 and 2. Lightning frequency is the yearly number of storms reported at 8 stations distributed over the system; lightning severity is the visual classification of storms by observers at these stations.

Outstanding features regarding outages (Table IV) are:

1. Outages on this system, averaging 10.6 to 12.4 per hundred miles of line per year, were practically the same for single- and double-circuit line during 1932 and 1933. This record differs from the situation in 1928 to 1931[6] when for the first 2 years 2-circuit outages were the greater, and for the second 2 years 1-circuit outages were greater (all on 100-mile-per-year basis).

2. Lines equipped with 2 ground wires had about 80 per cent of the outages experienced by lines with 1 ground wire.

3. Wood pole lines with no ground wires had approximately 50 per cent more outages than steel tower lines with ground wires.

4. Steel-tower ground-wire lines insulated for 132 kv, but operated at 33 to 44 kv, have in the order of 60 per cent of the outages of simi-

Table I—Miles of Line of 132-Kv Construction Operating on the American Gas & Electric Company System in 1933

Line right of way	1,457.2
3-phase circuit	2,484.4
2-circuit line	1,027.2
1-circuit line	430.0
Wood pole line	60.3
Line with 1 ground wire	1,247.0
Line with 2 ground wires	149.9
Line with no ground wire	60.3

Table II—Approximate Flashover Characteristics* (Kv) of Line Insulators

Insulator Units		60-Cycle	Minimum Impulse Values	
No.	Spacing (In.)	Dry (Crest)	1x5-μsec Wave	1 1/2x40-μsec Wave
10	4 3/4	640	880	680
11	4 3/4	700	980	750
12	4 3/4	780	1,080	830
10	5 1/8	680	950	730
11	5 1/8	765	1,050	810
12	5 1/8	850	1,150	890
9	5 3/4	680	950	730
10	5 3/4	760	1,040	860
12	5 3/4	895	1,250	1,025
10	6 7/8†	1,010	1,400	1,070

* Based upon "Flashover Voltages of Insulators and Gaps," Electrical Engineering, June 1934, p. 882–6, and effective spacing one unit less because of grading shields.
† No grading shields used.

Full text of a paper recommended for publication by the A.I.E.E. committee on power transmission and distribution, and scheduled for discussion at the A.I.E.E. Pacific Coast convention, Salt Lake City, Utah, Sept. 4–7, 1934. Manuscript submitted May 26, 1934; released for publication May 29, 1934. *Not published in pamphlet form.*

1. For all numbered references see bibliography at end of paper.

1 Item		2 Beaver Creek Hazard	3 Deepwater Pleasant-ville	4 Ft. Wayne Marion Muncie	5 Glenlyn Roanoke	6 Glenlyn Switchback	7 Howard Ashland	8 Howard Fostoria	9 Lima Ft. Wayne	10 Lima Fostoria	11 Logan Sprigg(3)	12 Marion Kokomo	13 Muncie Anderson	14 Philo Canton
Length of line	Miles	28.4	56.9	80.6	65.0	30.0	20.9	44.9	63.2	45.6	21.0	28.9	18.5	73.0
Insulators per Suspension String	No.-Space	10-5-1/8	10-4-3/4	10-5-1/8	10-4-3/4	11-5-1/8(2)	10-5-1/8	10-5-1/8	9-5-3/4	12-4-3/4(2)	10-6-7/8	10-5-1/8	10-5-1/8	11-4-3/4
Operating Voltage	K.V.	44	66	132	132	132	132	132	132	132	132	132	33	132
Ground Wires	No.	1	2	1	1	1	1	1	1	1	0	1	1	1
Grading Shields (1)	Type	R & R	R & R	R & R	R & R	R & H	R & R	R & R	R & H	None(11)	None	R & R	R & R	R & H
Height of Tower Peak (Standard)	Ft.	72	97	97	97	97	97	97	97	97	35(7)	97	97	97
Average Tower Foot Resistance	Ohms	-	45.5(8)	-	38.9	31.5	2.2	2.4	2.5	2.0	-	-	5.0	7.8
Average Towers per Mile	No.	3.74	5.66	5.68	4.13	4.26	5.85	5.70	4.78	4.70	7.76	5.69	5.74	4.07
Number of Circuits	No.	1	2	2	2	2	1	1(9)	1 (9)(13)	1(9)(10)(14)	1	2	2	2
1932 LIGHTNING PERFORMANCE														
Tripouts - One Circuit Only		0	5	3	4	0	1	1	3	0	2	0	1	3
Both Circuits		-	3	1	2	0	-	-	-	-	-	1	0	2
Damaged Insulators (Towers Affected)		0	0	4	5	0	0	0	3	-	9	-	-	0
" Conductors " "		0	1	2	5	0	0	0	1	-	8	-	-	3
Burned Arcing Rings " "		0	9	8	27	2	0	0	0	-	-	-	-	4
Total Cases of Damage (Towers Affected)		0	9	9	29	2	0	0	4	-	10	-	-	6
Cases of Damage per Line Outage		-	1.13	2.25	4.75	-	0	0	1.33	-	5	-	-	1.20
Lightning Storms Reported per Year														
Lightning Storms per Line Tripout														
1933 LIGHTNING PERFORMANCE														
Tripouts - One Circuit Only		2	2	9	5	2	0	4	5	1	4	0	0	2
Both Circuits		-	2	2	2	4	-	1	1	--	-	0	0	4
Damaged Insulators (Towers Affected)		0	0	3	3	2	0	0	2	2	-	-	-	2
" Conductors " "		2	0	3	5	1	0	0	1	0	-	-	-	2
Burned Arcing Rings " "		5	0	15	4	5	0	0	3	1	-	-	-	7
Total Cases of Damage (Towers Affected)		5	0	17	8	5	0	0	4	2	-	-	-	8
Cases of Damage per line Outage		2.5	0	1.8	1.8	0.84	-	0	0.8	2	-	-	-	1.33
LINE TRIPOUTS PER 100 MILES OF LINE PER YEAR														
1933		7.1	7.0	13.6	10.8	20.0	0.0	11.1	9.5	2.2	19.0	0.0	0.0	8.3
1932		0.0	14.1	5.0	9.2	0.0	4.8	2.2	4.8	0.0	9.5	0.0	5.4	6.8
1931		28.2	10.5	2.5	46.1	26.6	9.6	13.4	26.3	19.7	37.1	0.0	5.4	11.0
1930		10.6	14.1	11.2	16.9	16.7	4.8	4.8	2.2	2.2	23.8	6.7	16.2	5.5
1929		-	-	7.5	46.0	33.3	-	-	8.9	8.9	76.0	3.5	-	15.0
1928		-	-	-	10.8	6.7	-	-	-	2.2	42.9	-	-	16.4
1927		-	-	-	37.0	-	-	-	-	8.8	33.3	-	-	5.5
1926		-	-	-	48.0	-	-	-	-	19.8	31.0	-	-	20.5
Average		11.5	11.4	8.0	27.1	17.2	4.8	8.0	10.3	8.0	34.1	2.0	6.8	11.1
Ratio, Maximum to Average		2.5	1.2	1.7	1.8	1.9	2.0	1.7	2.6	2.5	2.2	3.3	2.4	1.9

(1) R & R means Ring & Ring
R & H means Ring & Horn
(2) One less Unit on Bottom Conductor
(3) Wood Pole Line
(4) Two less Units on Bottom Conductor
(5) No. 2 Circuit R & H
(6) R & H on #1 Circuit - R & R on #2
(7) Height of Steel Crossarm
(8) After Installing Ground Rods - Before Counterpoises
(9) Two Circuit Since June 5, 1933
(10) Part of Howard-Fostoria Line Since June 5, 1933
(11) R & R on New Circuit June 5, 1933
(12) Two Line Sections Since 1931, but Treated as One Line
(13) 10 - 5-1/8" Units on New Circuits
(14) 10 - 5" " " " " and R & R
(15) 10 - 5-1/8" and R & R on 2nd Circuit

lar lines operated at 132 kv. Similar better performance is shown on the one line operated at 66 kv, although in 1932 the outages were abnormally high because of several flashovers on the graded section of this line which should not be included in the over-all *line* performance.

The salient characteristic of line performance brought out in Figs. 1 and 2 is that line outages vary in unison with both the *total* storms observed (lightning frequency) as well as the number of very severe storms only; they do not correlate with either the number of *light* or *severe* storms alone.

Two-Circuit Outages

The use of 2-circuit lines as a means of improving continuity of service in our 132-kv network, until a year or so ago, has been fundamental. Two-circuit outages caused by lightning on such lines are shown in Fig. 3. These outages steadily increased from 1926 to 1932 as the system capacity grew and as the transmission system was extended through mountainous lightning-infested territory, rising from 15 per cent of the total line outages on 2-circuit lines in 1926 to 43.5 per cent in 1932. During 1933, however, these 2-circuit outages showed a decrease to 38 per cent, although 1933 was a worse year than 1932 in total storms and severe storms recorded, and also in total line tripouts.

This better 2-circuit performance in 1933 has been attributed to 3 causes: (1) The introduction of carrier current relaying to some 2-circuit lines thus eliminating some outages that may have resulted from through line fault currents; (2) the extensive application of high speed circuit breakers which

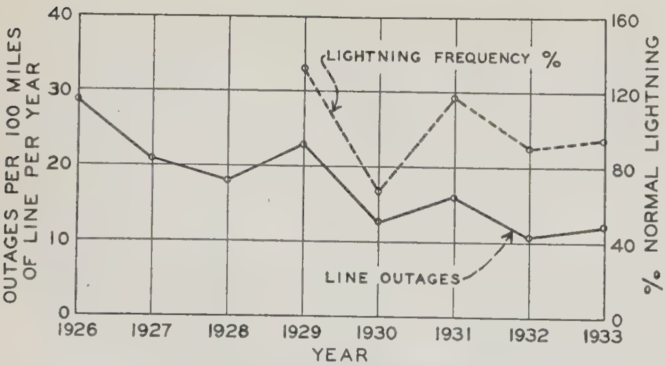


Fig. 1. Line outages on the transmission system of the American Gas and Electric Company compared with lightning frequency (per cent of average)

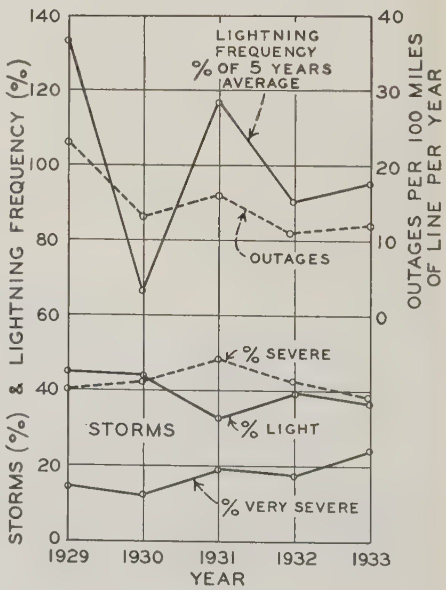


Fig. 2. Lightning frequency and severity as recorded at 8 stations compared with line outages

	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
lo ville aville	Philo So. Point Turner	Philo Howard	Roanoke Roxboro(12)	Roanoke Reusens	Saltville Kingsport	So. Bend Michigan City	So.Point Portsmouth	Sprigg Beaver Creek(3)	Switch-back Logan	Switch-back Saltville	Turner Cabin-Creek	Turner Logan	Twin Br. Benton-Harbor	Twin Br. Ft.Wayne	Twin Br. So.Bend	Windsor Canton
	167.2	80.7	98.3	43.0	56.0	40.0	34.5	39.3	50.0	38.8	23.6	40.2	38.0	65.4	4.9	55.0
-3/4	11-4-3/4(15)	10-5-1/8	11-5-1/8(2)	12-4-3/4(4)	10-5-1/8	9-5-3/4	10-5-1/8	10-5-3/4	10-5-1/8	10-5-1/8	10-5-1/8	10-4-3/4	10-5-1/8	9-5-3/4	9-5-3/4	10-4-3/4
	132	132	132	132	132	132	33	132	132	132	132	.132	132	132	132	132
	1	1	1	1	1	1	1	0	1	1	1	1	2	1	1	2
R(5)	R & H(6)	R & R	R & R	R & H	R & H	R & H	R & R	None	R & H	R & H	R & R	R & H	R & R	R & H	R & H	None
	97	97	97	97	97	97	97	?	97	97	97	97	97	97	97	78
	3.7	11.0	73.5	79.1								10.9		2.5		12.0
	4.10	4.93	4.47	4.65	4.15	4.59	4.43	5.52	3.78	4.50	4.23	3.36	5.49	4.61	4.9	8.84
	2	1	1	2	1	1	2	1	2	1	2	2	2	1	2	2
	8	3	24	4	7	5	2	7	8	16	1	2	2	7	2	1
	5	-	-	6	-	-	2	-	8	-	1	0	2	-	1	0
	3	1	2	1	0	7	2	5	5	0	1	2	3	13	4	-
	9	0	6	2	1	0	0	6	7	1	0	2	0	5	1	-
	20	2	22	21	5	2	5	-	13	16	1	5	7	9	2	-
	20	2	23	21	5	8	5	8	14	16	1	6	7	24	5	1
	1.54	0.67	0.96	2.1	0.76	1.6	1.25	1.14	0.89	1.00	1.00	3.0	1.75	3.43	1.67	1.00
	10	9	11	3	6	11	4	7	6	9	1	11	5	6	0	1
	4	-	-	2	-	-	3	-	7	-	3	3	4	-	0	0
	1	1	-	-	0	0	2	7	-	1	-	2	2	10	4	-
	0	0	-	-	1	0	1	5	-	1	-	2	0	3	4	-
	12	7	-	-	10	1	8	-	-	11	-	10	2	9	1	-
	13	7	-	-	10	1	8	7	-	11	-	11	3	21	8	-
	0.93	0.78	-	-	1.67	0.01	2.0	1.0	-	1.22	-	0.79	0.33	3.68	-	-
	8.4	11.2	11.2	11.6	10.8	27.6	20.3	17.8	26.0	20.2	17.0	26.4	23.7	9.2	0.0	1.8
	7.8	3.7	24.4	23.2	12.5	12.5	11.6	17.8	32.0	40.3	8.5	5.0	10.5	10.7	61.0	1.8
	19.4	6.2	36.6	60.5	16.1	15.0	26.1	43.2	34.0	90.5	17.0	24.5	10.5	15.3	0.0	3.6
	10.1	3.7	46.7	25.6	12.5	2.5	0	28.0	16.0	23.2	12.7	12.5	7.9	4.6	20.4	0.0
	16.3	-	32.5	37.2	23.2	22.5	-	--	40.0	34.8	29.6	37.4	-	10.7	61.2	3.6
	7.1	-	20.0	23.2	8.9	17.5	-	-	36.0	10.9	-	32.3	-	-	0.0	3.6
	5.9	-	24.6	37.2	-	10.0	-	-	-	-	-	57.2	-	-	41.0	3.6
	10.6	-	-	-	-	-	-	-	-	-	-	44.8	-	-	0.0	20.0
	10.7	6.2	28.0	27.3	14.0	15.4	14.5	26.7	30.6	36.7	17.0	30.1	13.2	10.1	23.0	4.8
	1.8	1.8	1.7	2.2	1.7	1.8	1.8	1.6	1.3	2.5	1.7	1.9	1.8	1.5	2.7	4.2

sometimes probably cleared the trouble on one circuit before it could be communicated to the second circuit; (3) the application of expulsion protective tubes to one 2-circuit line, for which the records show that in at least 3 instances the protected circuit cleared the line of lightning without circuit interruption.

Effect of Tower Footing Resistance

Benefits of low tower footing resistances in reducing lightning flashovers of lines having overhead ground wires have been discussed in the past on theory, and investigated to some extent by analyzing operating experience. The 2 years' operating record presented here gives supporting data to existing evidence.

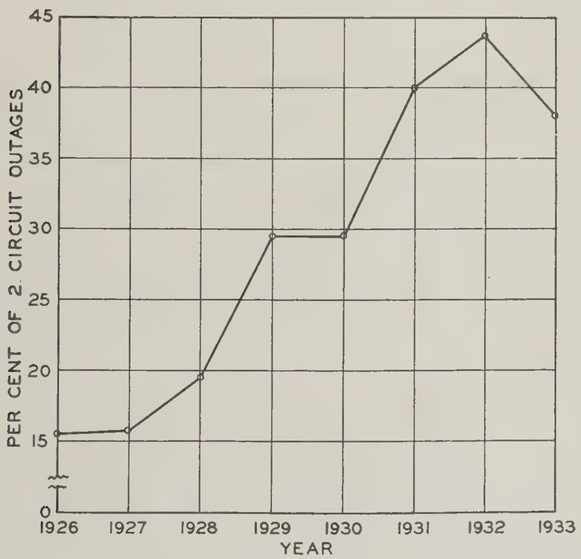


Fig. 3. Per cent of 2-circuit outages of 2-circuit lines during 1926–33

The effect of low average tower footing resistance on line outages is shown in Fig. 4. The drop from 30 outages per year to 8, as the average tower footing resistance falls from 80 to 5 ohms is too definite to be anything but conclusive. Although the plotted points are somewhat scattered, as might be expected from the different types of territory and variety of soil involved (the record covers 4 years' experience on 15 different lines), the trend in reduction of outages is clearly defined.

The magnitude of tower footing resistance required to make a line practically lightning proof has been much discussed, but rarely stated with any assurance; 10 ohms and 5 ohms have been mentioned as possibilities. Some light may be thrown on this by the data presented in Fig. 5. Here it is shown, that of the 86 towers flashed over in 1932 and 1933 on 5 typical lines, 57 per cent had a footing resistance of 10 ohms or less, 44 per cent 5 ohms or less, and 10 per cent 1 ohm or less.

While Fig. 4 shows the benefits of low tower footing resistance in reducing line outages, it is clear from Fig. 5 that tower footing resistances in the order of 5 or 10 ohms have little prospect of rendering practical conventional 132-kv lines of the type described herein lightning proof, but undoubtedly will make them more lightning resistant. Further analysis of Fig. 5, given in Table V, shows that

Table IV—Outages per 100 Miles of Line (Right of Way) per Year

	1932	1933
Total line outages	155	180
Average all lines	10.6	12.4
2-circuit lines, 1 ground wire	10.1	12.2
1-circuit lines, 1 ground wire	11.5	12.6
Lines with single ground wire	10.7	12.4
Lines with 2 ground wires	8.8	9.4
Wood pole lines, no ground wire	14.9	18.2
Lines insulated for 132 kv, but operated at 33 and 44 kv	5.7	9.1
Lines insulated for 132 kv, but operated at 66 kv	14.1	7.0

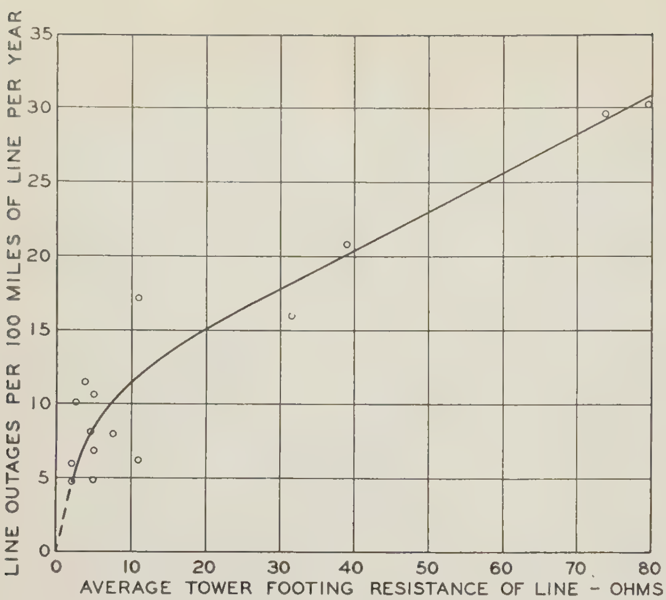


Fig. 4. Extent of tower footing resistance on line outages (4-year average on 15 lines, 1930–33)

considering the 86 flashed towers and one tower each adjacent, in 31 per cent of the cases the tower having the lowest resistance flashed, and in 37 per cent of the cases the tower having the highest resistance flashed.

Counterpoise Performance

On sections of 2 lines where the normal tower footing resistances were high, counterpoises were installed as previously described.[6] These line sections were too restricted in extent and have been in service too short a time to enable comprehensive conclusions to be drawn regarding the benefits of counterpoises in general. Observed flashovers on these line sections, however, have decreased since the installation of the counterpoise wires, as indicated in Table VI. On the Glenlyn-Roanoke (Va.) line, which in the past has had a bad lightning record, flashovers on the protected towers were reduced more than 50 per cent; on the Deepwater-Pleasantville (N. J.) line the reduction was 70 per cent.

Line Damage

Records of these lines since grading shields were installed, as in the past, show no serious damage to conductors, insulators, or hardware. No line has been out of service because of its inability to be placed back into service. The summarized record is shown

Table V—Towers Flashed Over on 4* 132-Kv Line 1932 and 1933 (Refer to Fig. 5)

	No.	Per Cent
Total towers flashed over (at insulator assemblies)	86	100
Towers flashed over where footing resistance was lowest of 3 consecutive towers (considering 1 tower each side of flashed tower)	27	31
Ditto, highest tower footing resistance	32	37

* Philo-Canton, Rutland-South Point-Turner, Roanoke-Roxboro, and Turner-Logan lines.

in Table VII; of the flashover marks observed (number of towers involved) 75 per cent was found on grading shields, 22.8 per cent affected conductors, and 29.5 per cent involved insulators. These percentages, while an average for the 2 years, are almost exactly the same for each year individually. The lesser number of observed flashovers in 1933, although a worse lightning year than 1932, is probably because complete inspections of all lines after the 1933 season have not been reported.

The "towers flashed over per line outage"—numerically 1.54 in 1932—seems to indicate that, on the average, in about 50 per cent of the cases the lightning disturbance has affected 2 towers. The corresponding figure of 0.84 for 1933 has been discounted because of the lack of complete line inspection, as indicated in the preceding paragraph.

Phase Location of Line Flashover

An analysis of the positions on the towers of conductors on which flashovers have occurred gives results that are interesting to interpret in the light of both lightning protection to the line and system stability as affected by single or multiphase faults.

Table VI—Flashovers on Counterpoise Sections of Line

Line	No. of Towers With Counterpoises	Towers Flashed Over: Before Counterpoises Were Installed	Towers Flashed Over: After Counterpoises Were Installed
Glenlyn-Roanoke 132 kv	40	6.2 (yearly avg)	3.0 (1 yr)
Deepwater-Pleasantville 132/66 kv	100	5.0 (yearly avg)	1.5 (2-yr avg)

Such an analysis has been made for several lines, using 2 methods: first, by flashover marks observed on tower climbing inspection on 5 lines (Table VIII); and second, by automatic oscillograph (Hall recorder) recording line voltage at a cardinal point on the system, thus observing line performance over a large section of the system from one central point. Records obtained by the latter method are summarized in Table IX.

Inspection at flashover locations (Table VIII) shows that, for the 2 years, the top conductor only was affected in 54.3 per cent of the cases, the middle conductor only in 15.5 per cent, and the bottom conductor only in 13.3 per cent, making a total of 83.1 per cent of faults involving one phase only. Of the remainder, apparent 2-phase flashovers accounted for 12.9 per cent and 3-phase faults 4.0 per cent of the total. These results are very similar to corresponding records of 1930 and 1931[6] where the figures were 86.4, 11.3, and 2.3 per cent, respectively.

Corresponding 1932–33 records of (Table IX) faults, as obtained graphically over about 1/3 of the system, showed 77.0 per cent single-phase faults, 13.4 per cent 2-phase faults, and 9.6 per cent 3-phase faults. The 3-phase fault data here probably err on the high side as nearly all were interpretations of oscillographic records of line disturbances where

little voltage drop was recorded, and the faults were remote from the points of observation. The 1930–31 record in Table IX obtained on one line close to an automatic current recording oscillograph showed only 6.6 per cent 3-phase faults, a figure which is probably more trustworthy, and more in line with the record obtained by physical inspection.

While diverse interpretation of the data in Tables VIII and IX may permit the justification of any existing theory of how lightning gets on the lines

Table VII—Line Damage

	1932	1933
Tower flashovers (insulators)	71	44
Towers with burned conductors	60	31
Tower flashovers (grading shields)	181	111
Total flashovers (towers affected)	242	149
Total line flashovers	157	180
Flashed over towers per line outage	1.54	0.83

of this system, there seems to be no evidence, from the data, that any one theory can be set up to the entire exclusion of any other. One outstanding point is the record of single-phase faults on middle conductors of vertically configurated lines, which comprise 15.5 to 25 per cent of the total faults. Similar past records[5,6] give results of the same order. It is clear that 2 ground wires—the normal ground wire, together with the top line wire (considered a ground wire for flashovers on the middle phase only)—with the conductor configuration employed on these lines, does not give complete shielding from lightning.

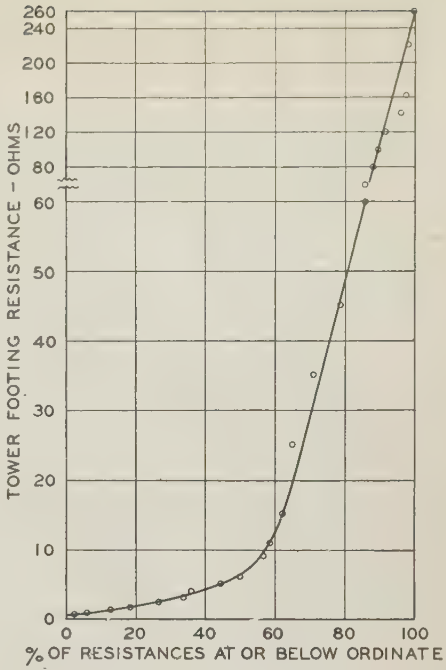
One interesting point brought out by the oscillograph records (Table IX) is that 7.8 per cent of the faults that start as single-phase develop into 2-phase faults; and 1.6 per cent of faults starting as 2-phase develop into 3-phase faults.

Apparatus Damage

Although station apparatus is not part of the lines, the operating record of such apparatus under lightning conditions is associated so closely as to be of interest. During 1932, 2 large 132-kv power transformers failed at stations equipped with lightning arresters, and graded insulation at line entrances. During 1933, there were failures of one power transformer where no lightning arrester or graded insulation existed, one lightning arrester (reduced to 50 per cent) but without other failure in the station, one cable capacitor, and an insulator on a lightning arrester.

Fig. 5. Effect of tower footing resistance on line flashover (86 towers where flashover was observed during 1932–33)

Data obtained on Philo-Canton, Roanoke - Roxboro, Philo - Howard, Philo - Rutland, So. Point, and Turner-Logan lines



Summary and Conclusions

Analysis of data presented in this and previous papers on the same 132-kv system, leads to the following conclusions:

1. Very definite decrease in lightning outages of transmission lines is effected by the use of a ground wire; a reduction in the order of 30% being indicated for 1932 and 1933.

2. Low average tower footing resistance of a line is productive of low lightning outages. Below 10 ohms the reduction is very pronounced.

3. Flashovers occur even at towers having low footing resistance; low resistance reduces outages but does not eliminate them.

Table VIII—Location of Flashed Over Insulator Assemblies by Tower Climbing Inspection

Line	1932 T	1932 M	1932 B	1932 T & M	1932 T & B	1932 B & M	1932 T, M, & B	1933 T	1933 M	1933 B	1933 T & M	1933 T & B	1933 B & M	1933 T, M, & B
Philo-Canton	5	0	0	1	0	0	1	6	1	0	0	0	0	0
Roanoke-Roxboro								2	8	7	4	1	1	0
Philo-Rutland-So. Point	14	0	2	1	1	0	1	11	1	1	0	0	0	0
Philo-Howard	0	0	0	1	0	0	1	3	2	1	0	1	0	0
Turner-Logan	3	0	0	1	0	0	1	5	2	1	0	1	0	0
Totals	22	0	2	4	1	0	4	26	14	10	4	3	0	0
Yearly %	66.7	0	6.1	12.1	3.0	0	12.1	45.6	24.6	17.5	7.0	5.3	0	0
Totals 1932 & 1933	48	14	12	8	4	0	4							
% of Totals	54.3	15.5	13.3	8.9	4.0	0	4.0							

	1932–33	1930–31
% Single phase	83.1	86.4
% 2 Phase	12.9	11.3
% 3 Phase	4.0	2.3

T, M, and B represent top, middle, and bottom assemblies, respectively.

4. It is impossible, practically, to overinsulate a line to prevent lightning outages. Overinsulation in the order of 3 or 4 to 1 for $^{33}/_{44}$ kv lines indicates a reduction in outages ranging as high as 50%.

5. On present day 132 kv lines, physical damage resulting from lightning flashover is of little concern where grading shield arcing protection is used.

6. From 75 to 85% of lightning troubles on these lines result in single phase faults only. The spread of trouble to other phases is infrequent.

7. Continuity of service can be bettered some 60% by the use of two circuit construction.

8. The possibility of producing a lightning proof line by the use of expulsion protective gaps at insulator assemblies, with our type of line construction, without going to additional ground wires, insulation, conductor clearances, or reduction in tower footing resistance seems possible, based on actual operating experience obtained on one line last year. Detailed results of this installation will be reported at a later date.

9. Although not directly brought out by the data in the paper, there is still another possibility of producing a high tension transmission line with the equivalent of lightning-proof performance and that is by the use of a high speed opening high speed reclosing breakers reclosing possibly in 10 cycles or less after the flashover, so that the net effect will be no loss of synchronism and no interruption of service to even the most sensitive equipment. Some development work on that idea now started will be reported on at a later date.

Table IX—Location of Flashed Over Line Conductors by Automatic Oscillograph-Hall Recorder

1932–1933	
Total records obtained	72
Records indefinite	8
Indefinite phase indication because of 2-line trouble	10
Analyzed for flashover phase location	52

	T	M	B	T & M	T & B	B & M	T, M, & B
Totals	17	13	10	2	3	2	5
Per cent	32.7	25.0	19.3	3.8	5.8	3.8	9.6

	1932 & '33	1930 & '31
% 1-phase faults	77.0	73.8
% 2-phase faults	13.4	19.6
% 3-phase faults	9.6	6.6
No. of 1-phase faults developing into 2-phase faults	5	7.8%
No. of 2-phase faults developing into 3-phase faults	1	1.6%

T, M, and B represent top, middle, and botton assemblies, respectively.

10. The effect of lightning on a transmission line is distinctly local, extending over only a very few towers, frequently not more than two, and in many cases only one.

11. Line outage performance follow both total storm frequency, as well as frequency of severe storms. This may be of value in predicting line performance.

12. Graphic automatic recording instruments have been of great benefit in studying the lightning performance and characteristics of these lines; as they show definitely, in many cases, what has taken place.

13. The benefits of counterpoises in reducing line outages due to lightning are indicated in a recorded reduction in flashed over towers in the order of $^1/_2$ to $^2/_3$.

The analysis of lightning performance of the 132-kv lines of the American Gas and Electric Company system which has been continued for the past 9 years has resulted in some very definite progress being made in understanding the lightning problem and also definite conclusions on many aspects thereof. The progressive stages of development of the more important ideas have been summarized in Table X. It may be noted that many of the controversial points have been settled, at least to the authors' satisfaction at the present time. Consequently, in the future attention will be concentrated on those phases of the lightning problem that remain unanswered or in controversy. There is, no intention, however, to discontinue or to relax in the thoroughness with which operating performance records on this system have been gathered and analyzed over almost a decade.

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Table X—Progress in Reaching Conclusions on Lightning Performance of 132-Kv Lines of American Gas & Electric Company

Ref. No.	Features Considered	Status in Year Indicated 1926	1927	1928	1929	1930 1931	1932 1933	Proved or Not Proved
1.	One ground wire effective in reducing lightning outages	A	C	P	C	C	C	P
2.	Two ground wires more effective than one in reducing lightning outages		D	D	P	C	C	P
3.	Low tower footing resistance reduces lightning outages	A	D	D	D	P	C	P
4.	Tower footing resistance must be considerably less than 20 ohms—in the order of 5 ohms suggested				D	C	P	P
5.	Low tower footing resistance does not make line *lightning proof*				A	D	P	P
6.	Grading shield protection of insulators render line damage of minor importance	A	D	P	C	C	C	P
7.	Grading shield protection reduce number of lightning flashovers		A	X	C			
8.	Effects of lightning on line is localized near point of origin (effect at stations not included)		A	D	P	C	C	P
9.	Lightning storm data—frequency and severity—must be evaluated in considering outage data		A	D	P	C	C	P
10.	Two-circuit lines improve continuity of service, but do not make lines lightning proof	A	D	P	C	C	C	P
11.	Continuity of service greatly enhanced by expulsion tube protection—lightning proof line seems possible						D	NP
12.	Overinsulating line, although improving performance, does not make line lightning proof					A	P	P
13.	Impulse insulation strength of wood does not give the great freedom from line outages predicted					D	D	NP
14.	Protection against induced lightning voltages is important	A	D	D	D	C	C	P
15.	Direct lightning strokes play vital part in producing line outages				D	C	C	P
16.	Lowering tower footing impedance by counterpoises beneficial—probably more so than low resistance					D	D	NP
17.	Installation of high speed tripping and reclosing circuit breakers						A	

A—idea advanced; C—confirmed; D—discussed; P—proved to authors' satisfaction; X—discarded. NP—Not proved.

Incandescence—

Some Theoretical Aspects

Some theoretical considerations involved in incandescent phenomena, with particular reference to incandescent illumination, are discussed briefly in this paper. In spite of the recent remarkable achievements in luminescent illumination, the incandescent lamp still is believed to await a genuine challenge.

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THE 2 CLASSES of radiation pertinent to a discussion of illumination are incandescence and luminescence. Many light sources fall partially into both classes, and therefore the line of demarcation is not always obvious. Indeed, it is believed that fundamentally they are identical, merely being different manifestations of energy release from atomic systems, disturbed by chemical, electrical, thermal, or other means. All electrons presumably have specific wave lengths at which they radiate. In solids and liquids, however, the molecules are packed so closely that they cannot vibrate in their proper periods. Just when one is beginning to emit regular vibrations, another knocks against it, and the vibrations become irregular. This results in vibrations of every wave length, our so-called continuous spectrum. Gas and vapor molecules being relatively free are not disorganized thus, and therefore the spectra of these are seen as series of lines (Fig. 1). If the pressure of the gas be increased enormously, it is conceivable that a continuous spectrum also might be produced, probably with the characteristic line spectrum superimposed on it.

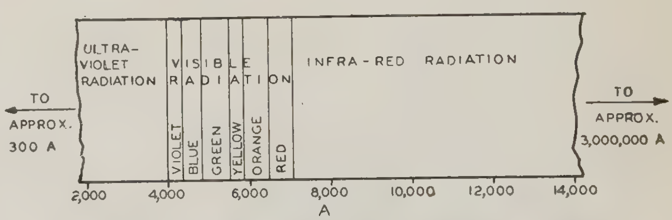
The specific field of this paper is incandescence, frequently called temperature radiation. As already noted, this type of radiation is characteristic of solids and liquids, and is characterized by continuous spectra. Only a few solids are known that are exceptions to this general rule of a continuous spectrum, and only one or 2 gases are known that at temperatures attainable in the laboratory will give forth radiation in the visible region through incandescence. All substances in the solid or liquid state start emitting visible radiation at temperatures just above 500 deg C, the exact temperature varying with the substance. At low temperatures, the maximum energy radiated is somewhere in the infra-red region; as the temperature is increased, the maximum shifts to a shorter and shorter wave length, theoretically reaching the visible or ultra-violet regions (Fig. 2). This was postulated originally by Wien, and now is known as Wien's displacement law.

For purposes of discussion, some standard is advisable, which, for temperature radiation, is called a "black body." This may be defined as a substance capable of absorbing every incident radiation in the ultra-violet, visible, and infra-red regions ranging from about 300 A to 3,000,000 A. (A is the abbreviation for Ångström unit, a unit used for expressing wave lengths of light; it is equal to 1 cm $\times$ 10^{-8}.) Actually, there is no such substance, since everything reflects some energy—from such things as lampblack and platinum black which are about 99 per cent perfect, to newly polished silver which is only a few per cent perfect. The carbon filament, which was used for many years in incandescent lamps, is also very nearly the equal of the black body standard. However, experimental artifices such as internally blackened spheres with minute observation hole may be used to reproduce black body phenomena even more closely than actual substances will. The obvious question that follows is why a standard of absorption should be chosen to discuss radiation.

Very early in the scientific history of light it was realized that some important relation existed between the absorption and emission of a body. It remained for Kirchhoff and Balfour Stewart, working independently just prior to 1860, to reduce this relation to a definite law, now named for the former. It may be expressed as follows: At a given temperature, the ratio between the emissive and absorptive power for a given wave length is the same for all bodies:

$$\frac{E_{\lambda T}}{A_{\lambda T}} = \text{constant}$$

Stated in another way, this means that any body that is a good absorber is a good radiator, and in just the same proportion. Fundamentally, Kirchhoff's law



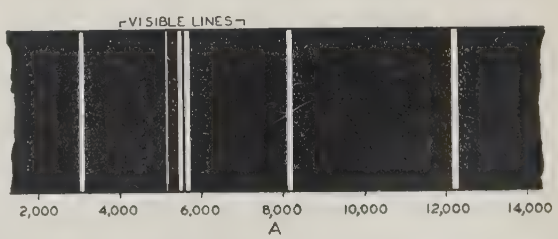


Fig. 1. Continuous spectrum of typical incandescent source (above) and (below) line spectra of typical luminescent source (sodium)

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proves that at a given temperature no substance can emit more light of a given wave length than a perfect black body at the same temperature. This does not necessarily mean that no substance may be more efficient than a black body as a light source, as may be seen in a later discussion. A second important conclusion from this law is that a body cannot emit those rays for which it is transparent, or for which its surface acts as a perfect mirror. Since the ratio of emission to absorption must remain a finite number, the substitution of zero for $A_{\lambda T}$ (the condition of perfect transparency or perfect reflectivity) must be followed by the substitution of zero for $E_{\lambda T}$. Still another conclusion is that when a body is capable of emitting certain radiations, it absorbs these same radiations when it is irradiated by them. It may absorb other radiations also, as is illustrated by the selective absorption of colored substances.

Mere radiation of energy, however, does not make a good light source. The effectiveness of visible radiations is wholly dependent on the mechanism of the eye. The average human eye has a very definite sensitivity curve which reaches its maximum at 5,560 A, but drops off very quickly to small values at the limits of the visible spectrum. This is shown by Fig. 3. Any radiations beyond these limits, of course, are worthless for vision, and within the limits are effective only in proportion to the ordinates of the curve.

As previously pointed out, the maximum energy radiated is at its peak in the infra-red regions at low temperatures. As the temperature increases this peak comes nearer and nearer to the peak of maximum eye sensitivity; if the latter peak could be reached, there would be obtained for any particular

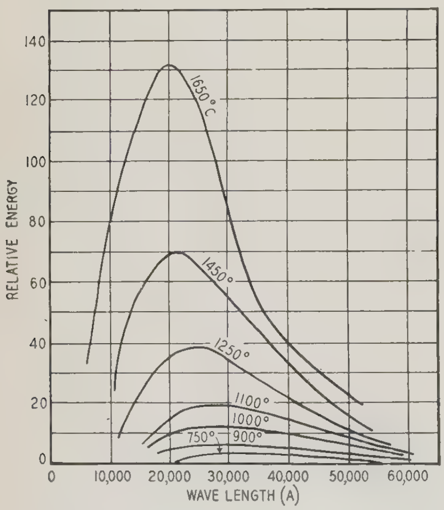


Fig. 2. Energy curves for radiations from a black body at various temperatures

material the most efficient incandescent light source that could be constructed. It is characteristic of all materials, however, that they do not absorb, and, therefore, *do not radiate*, energy at all wave lengths except, of course, a black body which does so by definition. Carbon radiation for example, is different from tungsten radiation which in turn is different from that of iron. This characteristic of individual materials is called selective radiation and is a very important factor in determining the effectiveness of a light source.

To these 2 light-source criteria of incandescence—good absorption (or good radiation) and selective radiation—must be added practical considerations. The material chosen must be capable of withstanding high temperatures for long periods of time and must be susceptible to processing for manufacture. A review of the history of incandescent sources will help to understand the full scope of the problems involved.

Almost all early forms of illumination were produced by chemical means—the burning of wood, of vegetable and animal oils, and later of mineral oils and gas. In the final analysis, these are forms of incandescence, usually of minute particles of carbon, although sometimes the phenomenon of luminescence also occurs. Naturally elementary incandescence was known through the process of putting a bar of metal into a fire until it became white-hot, and glowed upon removal; but the problem of maintaining the glow except by a fire that would give off more light than the indirectly heated bar was not solved until the advent of electricity.

As far as is known, the first application of electricity to produce incandescence was made by Sir Humphry Davy in 1802. By passing a heavy current through thin strips of metal, light was produced. He found only one metal, platinum, that would last long enough at an incandescent temperature to be called a light source. This was the forerunner of the modern filament lamp. Thereafter, for a period of 75 years, endless experimenters worked on this problem with 2 materials in especial favor as filaments, carbon, and platinum. Then came the first real success—Edison's carbon filament lamp. While contemporaries of Edison, working independently, achieved simultaneous or even prior results, his work on all phases of the problem even to that of designing constant voltage distribution systems, marked the start of the electric light industry.

Edison's lamp patents were based on 4 things: a high resistance filament operating in a vacuum maintained by a one-piece glass globe having all joints sealed by fusion of the glass. All except one of these are still primary considerations; that one, the vacuum, merely changed so that it might be better expressed as keeping deleterious gases or vapors away from the filament.

Naturally, as with any definite product, continuous efforts were made to improve its value. These efforts extended in many directions—from glass problems, manufacturing economies, and exhaust perfection to the ever-present question, the filament. Efforts were made not only to improve carbon, but also to find substitutes for it. The first of these was osmium, an extremely rare metal, developed as a filament material in Austria and Germany. Its improved efficiency was of the order of 75 per cent, but its scarcity and its fragility prevented its use from becoming universal. Next in line was tantalum—not as efficient as osmium, but more practical. Then came tungsten with an early efficiency of 7.5 lpw (lumens per watt) or more than double the efficiency of the carbon lamps then in use (1907).

In tungsten, a metal was discovered which was entirely practical. Abundant, it did not present any insurmountable difficulties toward purification and processing; and thus far, considered practically as well as scientifically, in spite of an intensive and systematic research during the past 25 years to which few products have been subjected, no other known material will do as well.

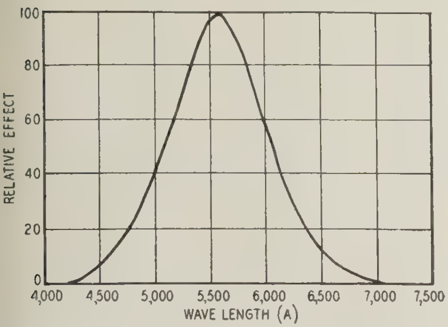


Fig. 3. Eye sensitivity for equal mounts of radiant energy

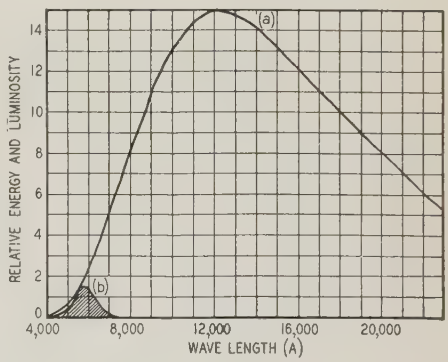
The filament material is, of course, the vital point of all incandescent lamp manufacture. However, other factors have great importance, some only because tungsten is used, others regardless of the material. Consider, for example, the question of high vacuum—a vital feature because oxygen, carbon dioxide, and water vapor must be kept away from the filament. After tungsten was adopted as a filament material, however, it was realized that the vacuum could be replaced by inert gases and definite improvement obtained. The presence of the gas retarded the evaporation of the tungsten, and thereby permitted the use of higher temperatures. At these higher temperatures, greater radiation in the spectral region is obtained. Greater heat losses (through conduction and convection) seemed imminent at first, but it was found that these heat losses even though greater were more than compensated by the additional light obtained, except in lamps of low wattage.

Assuming that tungsten is the best filament material available today, and that all major fields incident to its use have been explored and utilized, what is there to look forward to in efficiency? To raise the temperature of the filament increases its efficiency, but simultaneously shortens its life. From a practical standpoint, a life of about 1,000 hr for general service lamps seems to be desirable. At this standard, lamp efficiencies vary from 10 to 20 lpw. This seems to be unreasonably low when a theoretical computation based upon the mechanical equivalent of light indicates that the efficiency of a perfect light source would be in the neighborhood of 670 lpw. A study of the eye sensitivity curve (Fig. 3) indicates one aspect of this great difference. Let it be assumed that a light source were obtainable that would radiate wholly within the visible region. If this radiation were uniform in this narrow band, the illumination effect would be only in proportion to the ordinates of this curve, and therefore the efficiency would be about 220 lpw. Only a green light source radiating at 5,560 A could approach the figure of 670 lumens per watt; for a red light at 7,300 A, a perfect light source might have an efficiency only of the order of 20 or 30 lpw.

To speak of a practical light source radiating wholly within the visible spectrum is to speak of Utopia. Let the equivalent of an eye sensitivity curve (a spectral luminosity curve) be superposed on the complete radiation curve of a standard incandescent lamp (Fig. 4). A totalization of the areas enclosed under the curves indicates that an efficiency of 50 lpw would be excellent for tungsten temperatures a few hundred degrees less than its melting point of 3,650 deg C. In this connection it is interesting to observe that a black body would reach its maximum of luminous efficiency (approximately 90 lpw) at the temperature of 6,250 deg C; above this temperature, too much radiation is in the ultraviolet region, and below it too much in the infra-red. Even though many non-black bodies have a better selective radiation than a black body, a temperature of 6,250 deg C is so far beyond the limits of practice that approximately 50 lpw must be accepted as a theoretical peak efficiency for incandescent tungsten. Between this figure and the achieved 20 lpw illumination, engineers must look for improvement and explain the losses. Convection and conduction losses through the inert gases, the heating of lead wires and supports, absorption of light by the glass bulb—these are very appreciable factors, and apparently ones that in the weighing of lamp costs versus operating costs are at present in a state where only radical discoveries would make it economically wise to alter present lamps greatly.

Fig. 4. Spectral energy curve of a standard incandescent lamp (a) and spectral luminosity curve (b)

Area enclosed under the curve beyond the limits of the diagram is equivalent to approximately 30 squares



However, progress is by no means at a standstill. Ever since the adoption of tungsten the efficiencies of incandescent lamps have risen. During the present period they are taking an important step upward through the success of coiled-coil filaments. Just as the original coiled filament allowed higher temperatures, so the present development of a filament first wound as a simple helix, and then as a compound helix, is expected to increase efficiencies as much as 10 per cent by minimizing heat losses and allowing more radiant energy to be emitted in the spectral region.

In the face of remarkable achievements here and abroad in the field of luminescent light sources, most of them by the same manufacturers engaged in the

production of the filament lamp, incandescence might be thought to be on the defensive. A cold analysis, however, indicates that much greater progress than now even visioned must be made before the incandescent lamp ever can be regarded as a "back number." First of all, the purpose of any artificial source is merely to replace the light produced by the sun. It, too, is an incandescent source, probably with an efficiency equivalent to 50 or 60 lpw, and with the continuous spectrum common to all incandescent sources. With its endless possibilities of size and types, with its great simplicity of installation and operation, with its low cost, the incandescent lamp still awaits a genuine challenge.

Low Pressure Gaseous Discharge Lamps—Part I

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Radiation and conduction phenomena in low pressure gaseous discharge lamps are discussed in this paper. Results of measurements on the variables in a discharge are given, and an attempt is made to correlate them with the concentration of atoms at different energy levels, and with the luminous efficiency. An insight into the fundamental processes which occur in a gas discharge and govern the production of light in low pressure discharges are given. In Part I, which follows, radiation processes are discussed, and in Part II, scheduled for publication in the next issue, electrical conduction processes are covered.

WHILE the light from an incandescent solid, such as a tungsten filament, is characterized by a continuous type of spectrum, that is, one in which radiations of all wave lengths in the visible range are present, that from a gas or vapor has a characteristic line type of spectrum. As a result, the latter usually exhibits a distinct color due to the predominant intensities of radiations of certain wave lengths. The efficiency of such a light source depends upon both the intensities and the visibility factors of the most prominent lines.

In Fig. 1[1] are shown the spectra, as observed by passing the light through a prism spectroscope, of those gaseous discharges which have been utilized for purposes of illumination. The figure also gives the values of the visibility factor V_λ for the most intense lines in these spectra, and there is also shown a plot of V_λ as a function of λ. The light output L in lumens per unit area of a source is given by the relation

$$L = 621 \int_{\lambda_1}^{\lambda_2} V_\lambda E_\lambda d\lambda \qquad (1)$$

where $E_\lambda d\lambda$ denotes the energy radiated in watts per square centimeter in the range λ to $\lambda + d\lambda$, and 621 is the maximum luminous equivalent per watt of radiated energy (corresponding to radiation of wave length $\lambda = 5{,}550$ A = 555.0 millimicrons). (One Ångström unit = 1A = 10^{-8} cm = 0.1 mμ. One micron = 1μ = 10^{-4} cm.) The limits λ_1 and λ_2 for visible light may be assumed, for all practical purposes, to be $\lambda 4{,}100$ and $\lambda 7{,}200$. For any source, the specific luminous efficiency L_s is thus defined by the relation

$$L_s = \frac{L}{W} = \frac{621 \int_{\lambda_1}^{\lambda_2} V_\lambda E_\lambda d\lambda}{\int_0^\infty E_\lambda d\lambda} \qquad (2)$$

where W is the total energy radiated.

For any given source of light there also exists an optimum luminous efficiency L_0 which represents the efficiency of a fictitious source which has the same energy distribution in the visible region, but which emits no energy whatever outside the visible region. This is defined by the relation

$$L_0 = L/W_L = L/\int_{\lambda_1}^{\lambda_2} E_\lambda d\lambda \qquad (3)$$

and determines the maximum attainable efficiency for a light of a given energy distribution in the visible range.

Table I gives data on the luminous efficiencies (lumens per watt) of a number of light sources including the different types of gaseous discharges which are of practical interest. The last column gives the energy utilization ratio

$$\eta = L_s/L_0 = W_L/W \qquad (4)$$

for each case.

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1. *G. E. Rev.*, v. 37, 1934, p. 260–8.

For helium and carbon dioxide no data are available for making an estimate of the value of L_0, but undoubtedly the value of η for both cases is less than 0.05. The value of L_s for cadmium is typical of results obtained with other metal vapors such as those of lithium, potassium, rubidium, caesium, zinc, and magnesium. Of the rare gases, only neon and helium give sufficient light in the visible range to be of interest.

Only in the case of carbon dioxide is the light actually white, so that the use of this gas discharge has been suggested for true color rendering. In fact, it was used by D. McFarlan Moore in his tube lighting introduced about 1906. However, the use of gases, such as carbon dioxide, nitrogen, and hydrogen, has not proved practical because of the 2 disadvantages: first, the relatively low luminous efficiencies; and, second, the phenomenon of "clean up" which leads to a rapid disappearance of the gas during the operation of the discharge.

Table I—Luminous Efficiencies of Various Sources of Light

Source	Color	L_0	L_s	100η
Black body at T = 6,500	White	218.5	86.3	39.5
Sun	White	250[a]	100	40
Tungsten (gas filled)	White	143[a]	15 – 30	10 –20
Flaming arc	White	220[b]	27 – 45	12 –20
Sodium vapor	Yellow	475[c]	50 –100	10 –21
Mercury, low pressure	Blue-green	248[d]	15 – 20	6 – 8
Mercury, high pressure	Blue-green	298[a]	30 – 35	10 –12
Neon	Orange-red	198[d]	15 – 40	7.5–20
Helium	Yellow-white		4 – 10	
Carbon dioxide	White		2 – 4	
Cadmium	Blue		0.5– 1	

a. Values given by L. J. Buttolph, paper read before Am. Electrochem. Soc., April 1934.
b. Assuming that most of the light is due to the carbon crater, the temperature of which corresponds to that of a black body at 4,000–5,000 deg K.
c. Based on $V\lambda$ for the D-lines.
d. Values calculated by F. A. Benford from measurements under operating conditions.

A consideration of the data in Table I naturally leads to an investigation of the factors that determine the luminous output and efficiency of a gaseous discharge. In the following sections, an attempt will be made to discuss these factors in detail.

Origin of Spectral Lines

When a discharge is passed in sodium vapor at low pressure (0.0005 to 0.005 mm of mercury), the spectrum is obtained as a result of the impact on sodium atoms of electrons which have acquired kinetic energy from the electric field between the cathode and anode. If e denotes the charge on an electron, and V the potential difference through which the electron has traveled before collision with a sodium atom, the kinetic energy acquired is given by the relation

$$\frac{1}{2}mv^2 = Ve \tag{5}$$

where m = mass of electron and v = velocity.

For a potential fall of one volt, the velocity attained is 5.935×10^7 cm per second, and the kinetic energy is 1.591×10^{-12} ergs.

The complete arc spectrum of sodium is obtained only if the value of V exceeds that of the ionizing potential V_i, which in the case of sodium is 5.12 volts. At lower voltages than this, fewer spectral lines are obtained, and if the electron energies are reduced to some value corresponding to that between 2.10 and 3.18 volts only the 2 D lines (λ5,890 and λ5,896) are obtained. Collisions of sodium atoms with electrons having an energy below 2.10 volts are absolutely ineffective in producing any radiation from the sodium atoms.

The interpretation of these observations on the basis of the Bohr theory of atomic energy levels is illustrated by reference to Fig. 2. An electron of kinetic energy less than 2.10 volts suffers an *elastic* collision with a sodium atom, so that the electron loses only an insignificantly small fraction of its energy. On the basis of ordinary dynamics it is readily shown that this loss is $2m/M$ of the total energy of the electron, where M/m denotes the ratio of the mass of the atom to that of the electron. For sodium, $2m/M = 4.8 \times 10^{-5}$ volts. When the energy of the electron exceeds 2.10 volts, an *inelastic* collision occurs, and if the kinetic energy is less than 3.18 volts, there is a transfer of energy to the atom corresponding in amount to 2.10 volts, while the excess over this value is retained by the electron as kinetic energy. The energy imparted to the sodium atom is used to excite it to the *first excited state*, which is designated spectroscopically as the 3P state. When the atom is in such a high energy state, it tends to return *spontaneously*, within an interval of approximately 10^{-8} sec, to the normal state, and in this process the excess energy is radiated as a monochromatic radiation of frequency, ν, determined by the relation

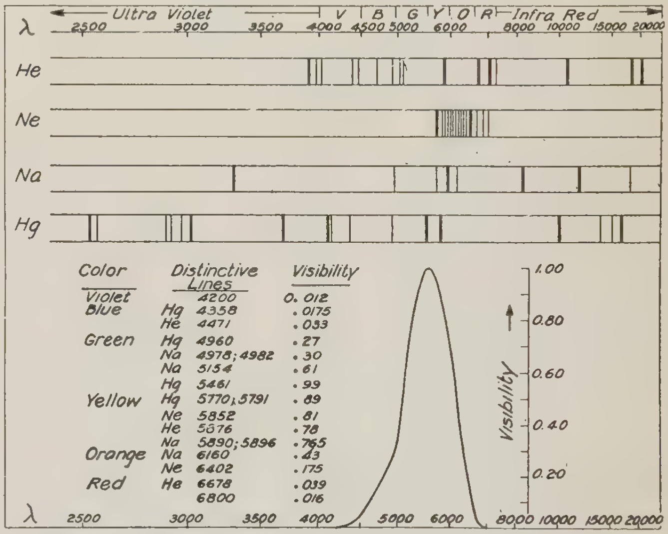


Fig. 1. Some typical line spectra and visibility curve

$$\nu = \frac{Ve}{h} = 2.43 \times 10^{14} \text{ per volt} \tag{6}$$

where h is Planck's constant (6.547×10^{-27} erg-sec),

and the corresponding wave length in Ångströms is

$$\lambda = \frac{c}{\nu} = \frac{12{,}336}{V} \tag{7}$$

where c = velocity of light.

Thus for $V = 2.10$ volts, λ, calculated from eq 7, has the value 5,890. Actually the $3P$ state of sodium

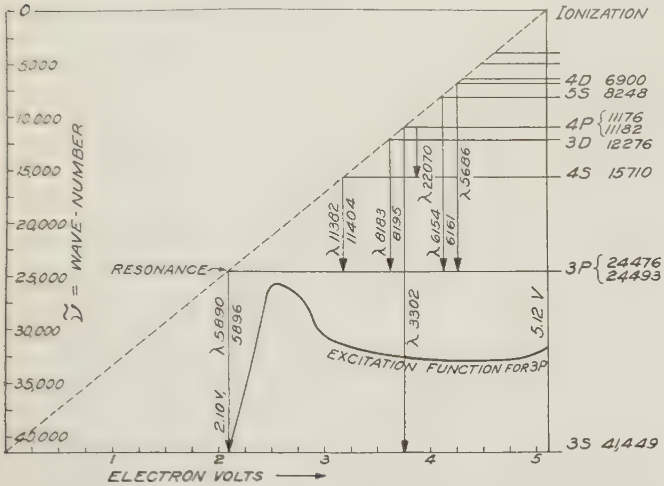


Fig. 2. Energy states and excitation potentials for sodium

consists of 2 states of slightly different energy contents. This accounts for the observed emission of the 2 lines known as D_1 and D_2, and having the wave lengths 5,896 and 5,890, respectively.

At 3.18 volts, the electron can excite a sodium atom to the $4S$ state and from this state the only transition which can occur is that to the $3P$ state, with the accompanying emission of the infra-red lines λ11,382 and λ11,404. Thus, as the kinetic energy of the electron is increased, it becomes possible to excite the sodium atom to successively higher energy states, and the spectrum changes from the simple doublet consisting of the 2 D lines to a spectrum containing more and more lines, until finally for $V = 5.12$ volts, or higher, all the lines in the arc spectrum of sodium appear. At this voltage, the atom becomes ionized, forming Na^+, and hence 5.12 is designated as the ionization potential (V_i).

While Fig. 2 shows the voltages at which the different energy states are produced, Fig. 3 shows, in a more customary form, the "energy levels" and the spectral lines corresponding to transitions between these levels. For reasons which need not be discussed here, transitions can occur only between levels in adjacent columns and not between those in the same column. Even before Bohr suggested his theory, spectroscopists had observed that in the simpler spectra it was possible to represent the reciprocal of the wave length of any line (wave number) as the difference between 2 wave numbers in the form

$$\frac{1}{\lambda} = \tilde{\nu}_1 - \tilde{\nu}_2 \tag{8}$$

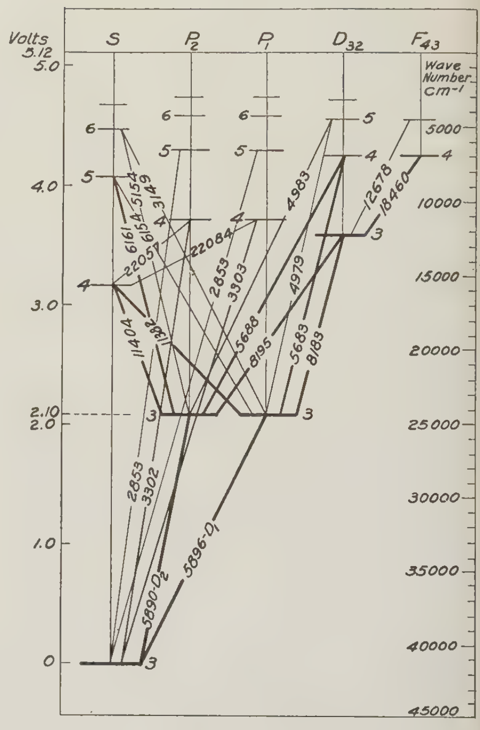
where $\tilde{\nu}_1$ is the wave number of the *lower*, and ν_2 that of the upper level. For members of the same series ν_1 is a constant, while ν_2 decreases as the limit of the series is approached. In Figs. 3 and 4 the wave numbers of the different levels have been indicated, and from the difference in wave numbers of any 2 levels, the corresponding electron volts may be derived by means of the relation

$$V = \frac{\tilde{\nu}_1 - \tilde{\nu}_2}{8{,}106} \tag{9}$$

Resonance Radiation and Resonance Potential

An interesting phenomenon observed with the D-line radiation of sodium is the "reversal" of these

Fig. 3. Energy levels and lines in arc spectrum of sodium



lines if a heated bulb containing sodium vapor is interposed between the sodium lamp and the observer. Similar reversal of spectral lines has been observed in the spectrum of the sun (Fraunhofer lines) and the explanation in both cases is the same. A sodium atom may be excited to the $3P$ state not only by collision with an electron of the requisite kinetic energy, as discussed above, but also by *absorption of light* of the same frequency as that emitted by the transition from $3P$ to the normal state. The absorbed energy is then reëmitted when the atom returns to the normal state, and in the case of a bulb containing sodium vapor, there is perceived in a direction at right angles to that of the incident light from the discharge, a faint yellow glow. The analogy with resonance phenomena in other fields of physics has led to the designation of this radiation as of the resonance type, and hence the corresponding excitation voltage, 2.10 volts for sodium vapor is known as the resonance potential (V_r).

This "absorption" of the D-lines by sodium thus is not a true absorption in which the radiation is converted into energy of a longer wave length, but rather

a scattering of the incident light. We may regard the phenomenon as one in which a photon, or light particle, of magnitude $h\nu_0$ (where ν_0 = frequency of D-lines) is passed on from one sodium atom to another, causing successive excitation and reëmission of the lines until finally the radiation is emitted at the surface of the discharge tube. From this point of view the phenomenon has been designated as "imprisonment of radiation."

Similarly a sodium atom in an excited state higher than $3P$ could be excited to a still higher state by absorption of radiation of frequency ν_{kj} where k designates the upper level j, the lower level, and ν_{kj} is the frequency of light emitted by a transition from the upper to the lower level. In a subsequent section this phenomenon will be discussed in greater detail because of its importance in determining the luminous efficiency of a light source.

The remarks have been limited so far to a discussion of the processes which lead to the production of radiation from sodium vapor, but this case has been used merely as an illustration of the type of mechanism by which the line spectra of all the elements are produced. During the past 20 years, since Bohr first postulated his theory, an enormous number of investigators have succeeded in interpreting the spectra of nearly all the elements, both in the normal state (arc spectra) and in the ionized state (spark or enhanced spectra); for an atom in the ionized state may be excited by impact of electrons to emit a characteristic spectrum, and in some cases it has been possible to determine the spectra of the atom in a number of stages of ionization. However, since these spectra are always in the ultra-violet region and require special conditions for their production they are not of interest as sources of light and will not be discussed further.

Various methods have been used to determine the energy levels in the arc spectra of the elements. In many cases the values of the potentials have been measured at which electrons lose discrete amounts of kinetic energy by collision with the atoms. Such measurements have yielded values known as critical potentials. A determination of the resonance lines by absorption measurements has made it possible to determine in some cases the energy values of the lowest excited states (V_r) and from these in turn the accurate values of the ionization potentials (V_i). This method has been used especially in the case of the rare gases and of a number of metallic vapors. Finally, an analysis of the arc spectra themselves combined with experiments on critical potentials have enabled spectroscopists to deduce the corresponding energy level diagrams.

As a result there is now available a great deal of information on the type of spectrum obtainable from each element and its system of energy levels. From an inspection of such energy level diagrams, as that shown in Fig. 3 for sodium, it is possible therefore to deduce some conclusions regarding the probable characteristics of any element as a source of light. (The theory of the origin of spectral lines is discussed in any treatise on modern physics. A very complete bibliography of papers published during 1920–1931 on line spectra of the elements is given in a paper by R. C. Gibbs.[2] Energy level diagrams of a number of elements are also given in a book by W. Grotrian.[3] See also review by S. Dushman.[4])

In Fig. 4 is shown the energy level diagram for the arc spectrum of mercury. The levels are arranged in columns according to spectral type, and the potentials required to excite these levels are indicated at the left, while the corresponding wave numbers are indicated along the line which divides the "triplet" system of levels from the "singlet" system. There are 2 respects in which the spectrum of mercury differs from that of sodium. First, the resonance lines, λ2,537 and λ1,850, are in the ultra-violet region, and lines in the visible range are produced only by transitions from higher levels to the lowest excited levels. Hence, in order to obtain λ5,461, an intense line in the green which is most efficient because of its high value of V_λ, it is necessary to

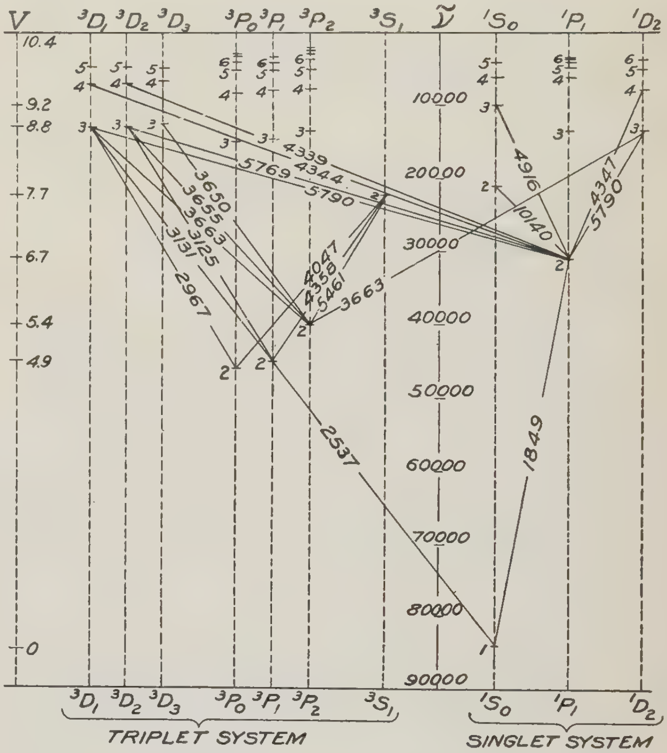


Fig. 4. Energy levels for mercury

impart to an electron a kinetic energy corresponding to 7.7 volts, while the radiation emitted corresponds to 12,336/5,461 = 2.26 volts. On the other hand, in the case of sodium, the kinetic energy of a 2.10 volt electron may be converted quantitatively into the radiation λ5,890, λ5,896.

Second, while in the case of sodium (and other alkali metals) all the energy states are of such a nature that a transition to a lower state may always occur with accompanying emission of radiation, there are certain energy levels in the case of mercury from

2. *Rev. of Modern Physics*, v. 4, 1932, p. 278.
3. "Graphic Representation of the Spectra of Atoms and Ions With One, Two, and Three Valence Electrons" (a book). Julius Springer, Berlin, 1928.
4. "Line Spectra and the Periodic Arrangement of the Elements." *Chem. Rev.*, v. 5, 1928, p. 109.

which no transitions occur with emission of radiation. Such are the states designated spectroscopically in Fig. 4 as 2 $^3P_0$ and 2 $^3P_2$, which are adjacent to the level 2 $^3P_1$ from which the transition λ2,537 occurs. These are known as metastable states and while the normal atom may be excited to one of these states by impact of an electron having the

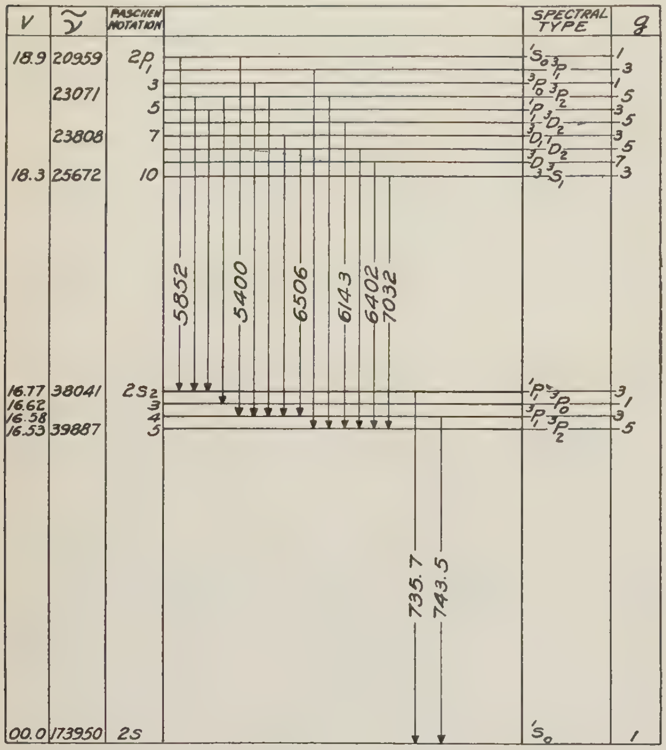


Fig. 5. Lower energy levels in spectrum of neon

proper value of kinetic energy, the life of the atom in a metastable state is of the order of 10^{-3} to 10^{-4} sec, instead of 10^{-8} as in the case of other excited states.

In Fig. 5 are shown (schematically and not to scale) the lower levels in the spectrum of neon. The lowest excited levels are known as s_5, s_4, s_3, and s_2 (or $^3P_2$, $^3P_1$, $^3P_0$, and $^1P_1$, respectively), of which s_5 and s_3 are metastable, while s_4 and s_2 give rise to the 2 resonance lines λ743 and λ736 which are in the far ultra-violet. The combination of these 4 levels with the 10 higher p levels give rise to about 30 spectral lines which impart to neon its red-yellow light. Here, as in the case of mercury, it is evident that the electron must acquire about 18.5 volts in order to excite a neon atom to a level from which transitions (corresponding to about 2 volts of kinetic energy) can occur with emission of visible light.

Finally, Table II gives values of V_i and V_r for a few of the gases and vapors of interest in the production of light, also the resonance lines (λ_r) and, in the column under V_m, the metastable levels.

From this table it is evident that of the different alkali metals, sodium is the only one which has resonance lines in the visible range. Also, while the resonance lines for the other alkali metals are in the near infra-red, the corresponding lines for all the other gases and vapors are in the ultra-violet. Since, under the usual operating conditions, the most intense lines in the arc spectrum of any element are the resonance lines, it follows that sodium must be more efficient as a source of light than any of the other elements. The other interesting fact, emphasized by the data in Table II, is the presence of metastable states in all other spectra than those of the alkali metal.

Probability of Excitation and Ionization

The various factors which govern the intensity and efficiency of light produced from an electrical discharge in a gas will now be considered. The intensity of any spectral line depends in the first place upon the rate at which transitions occur from some excited state k to a lower state j. Under stationary conditions, the rate at which atoms in state k revert to state j will be equal to the rate at which they are formed. Therefore the intensity of light must vary with both the electron current (I_e) and the concentration of atoms in the lower state j, (N_j), since the number of collisions per unit time per unit volume will vary with the product $N_j \cdot I_e$. However, not all collisions between sodium atoms and electrons of kinetic energy 2.10 volts (or higher) are effective in producing excited atoms in the $3P$ state. The probability that a collision will result in a transfer of energy is a function of the velocity (or kinetic energy) of the electron. It is customary to define the probability of excitation P_e, as the number of excited atoms formed per unit electron current per unit length of path, per unit pressure at zero deg C. For each energy level in any given spectrum, the manner in which P_e varies with V (i. e., with the kinetic energy of the electron) may be quite different. In Fig. 2 there is shown a plot of this function for the $3P$ state of sodium,[5] from which it is seen that the maximum probability of excitation

5. L. E. Loveridge, quoted by R. B. Brode, *Rev. of Modern Physics*, v. 5, 1934, p. 269.

Table II—Critical Potentials, Resonance Lines, and Metastable Levels

Atom		V_r	λ_r	V_m	V_i
Lithium	(Li)	1.84	6,708		5.37
Sodium	(Na)	2.10	5,890; 5,896		5.12
Potassium	(K)	1.60	7,645; 7,699		4.32
Rubidium	(Rb)	1.56	7,800; 7,948		4.16
Caesium	(Cs)	1.38; 1.45	8,521; 8,943		3.87
Helium	(He)	20.91	592	19.77	24.47
		21.12	584	20.55	
Neon	(Ne)	16.58	744	16.53	21.47
		16.77	736	16.62	
Argon	(A)	11.56	1,067	11.49	15.69
		11.77	1,048	11.66	
Krypton	(Kr)	9.98	1,236	9.86	13.94
		10.59	1,165	10.51	
Xenon	(Xe)	8.39	1,469	8.28	12.08
		9.52	1,295	9.40	
Zinc	(Zn)	4.01	3,076	3.99	9.36
		5.77	2,139	4.06	
Cadmium	(Cd)	3.78	3,261	3.71	8.96
		5.39	2,288	3.93	
Mercury	(Hg)	4.87	2,537	4.64	10.38
		6.67	1,850	5.44	
Thallium	(Tl)	3.27	3,776	0.96	6.07
		4.46	2,768		

occurs for electrons of 2.5 volts, approximately. In the case of the 2 $^1P_1$ state of mercury (corresponding to $V_r = 6.67$ volts), P_e increases from zero at 6.67 volts to a maximum value at 6.8 volts and then decreases with further increase in voltage.[6]

In a similar manner, the probability of ionization, P_i, is defined as the number of ions formed per unit electron current, per unit path length, per unit pressure at zero deg C. For values of V less than about 4 V_i, P_i increases linearly with V according to a relation of the form

$$P_i = C(V - V_i) \quad (10)$$

From the results obtained by I. Langmuir and H. A. Jones,[7,8] the following values of the constant C are derived for helium, neon, argon, and mercury. The value for sodium has been taken from a paper by M. J. Druyvesteyn and N. Warmoltz.[9]

Helium	(He)	0.035
Neon	(Ne)	0.034
Argon	(A)	0.33
Mercury	(Hg)	0.69
Sodium	(Na)	0.66

As has been shown by C. G. Found,[10] eq 10 is valid even for cumulative ionization (see discussion below) if V_i is replaced by V_r.

Intimately connected with the probability of excitation is the optical excitation function, F_e, which gives the intensity of any spectral line as a function of the kinetic energy of the incident electron, and which may be determined quite readily experimentally. This concept was first suggested by R. Seeliger[11, 12, 13] and determinations of F_e for a number of lines in different spectra have been carried out by several investigators, notably by W. Hanlé and K. Larche.[14] In Fig. 6 are shown curves obtained by the latter for the 3 lines in the spectrum of cadmium, $2^3P_2 - 2^3S_1$; $2^3P_1 - 2^3S_1$; and $2^3P_0 - 2^3S_1$ which correspond, respectively, to the lines λ5,461, λ4,358, and λ4,047 in the spectrum of mercury (see Fig. 4).

If the probability of a transition from state k to state j is designated by A_{kj}, then it is evident that the function F_e is given by the relation

$$F_e = P_e A_{kj} \quad (11)$$

which states that the intensity of any spectral line, ν_{kj}, varies with both the probability of excitation of the level k and the probability of transition from this level to state j.

A further consideration of the excitation function shows that this involves implicitly another quantity, the probability of a collision (P_c) between an electron of kinetic energy, V, and a molecule of the gas. (Since only monatomic gases and vapors are being considered the terms atom and molecule are evidently synonymous.) Actually the probability of a collision is also a function of V, as shown in Fig. 7[15] for collisions of electrons with atoms of the alkali metals.

6. W. H. Brattain, *Phys. Rev.*, v. 34, 1929, p. 474.
7. *Phys. Rev.*, v. 31, 1928, p. 357.
8. K. T. Compton and I. Langmuir, *Rev. of Modern Physics*, v. 2, 1930, p. 123.
9. *Phil. Mag.*, v. 17, 1934, p. 1.
10. *Phys. Rev.*, April 15, 1934.
11. *Ann. d. Physik*, v. 59, 1919, p. 613.
12. *Physikal. Zs.*, v. 22, 1921, p. 610.
13. "Gasentladungen," R. Seeliger, p. 32.
14. *Zs. f. Phys.*, v. 67, 1930, p. 440.

The function P_c is defined as the number of collisions per unit electron current per unit length of path per unit pressure at zero deg C.

The functions P_e, P_i, and P_c each determine a mean free path which is derived as follows:[5]

The probability of a collision in a distance dx in a gas at a pressure p is $P_c p dx$. A current of electrons of strength I passing through the layer dx is decreased by

$$dI = -IP_c p dx$$

Hence

$$I = I_0 \epsilon^{-P_c x p} \quad (12)$$

where I_0 is the initial electron current in the beam and I is the electron current after passing a distance, x, through the gas at a pressure, p.

The mean free path L is the average distance traveled before colliding and is given by

$$pL = 1/P_c = L_0$$

the free path at unit pressure.

From the value of L or L_0 the effective area of a single atom, q, is found by dividing P_c by the number of atoms per unit volume per unit pressure. If the unit of pressure is one millimeter of mercury at zero deg C, and the unit of volume is one cubic centimeter, then

$$q = 0.281 \times 10^{-16} P_c \text{ cm}^2 \quad (13)$$

The radius r of a circle of this area may be described as the effective radius of the atom for collision and is given approximately by

$$r = 0.3 \times 10^{-8} \sqrt{P_c} \text{ cm} \quad (14)$$

Table III gives values of mean free paths for electrons (L_e) and molecules (L_m), also values of $1/L_e$ and $1/L_m$, the number of collisions per centi-

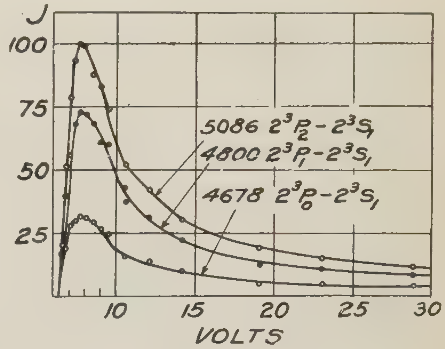


Fig. 6. Intensities of lines in spectrum of cadmium as functions of electron volts

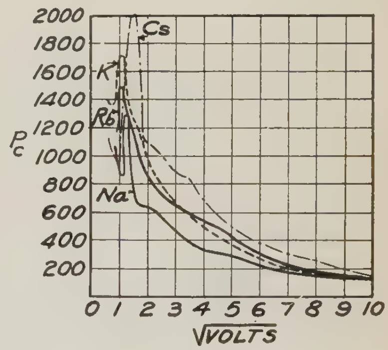


Fig. 7. Collision probabilities for electrons in alkali metal vapors, as functions of velocity

15. R. B. Brode, *Rev. of Modern Physics*, v. 5, 1934, p. 269.

meter path, for a few gases at one millimeter pressure and 25 deg C.[16] According to the kinetic theory of gases $L_e = 4\sqrt{2}L_m$.

Table III—Kinetic Theory Values of L_e, L_m, and their Reciprocals at p = One Millimeter and 25 Deg C

Gas		L_e	L_m	$1/L_e$	$1/L_m$
Mercury*	(Hg)	0.0149 cm	0.00263 cm	67.0	380.0
Argon	(A)	0.0450	0.00795	22.2	125.9
Neon	(Ne)	0.0787	0.01390	12.7	72.0
Helium	(He)	0.1259	0.02221	7.95	45.0

* The vapor pressure of mercury at 25 deg C is 0.00184 mm. Hence the values of L_e and L_m at this temperature should be multiplied by $1/0.00184 = 544$.

If these values be regarded as the significant ones from the point of view of collision, then the values of $L_eP_e = L_e/L_0$, and L_eP_i are to be considered as measuring the probability that excitation or ionization shall occur at any one collision. Thus for electrons of kinetic energy corresponding to 22.0 volts in neon, the value of $1/P_i = 59$ cm, while $L_e = 0.0787$ cm. Therefore the probability that an electron of this energy will ionize a neon atom at a single collision is $0.0787/59 = 0.00134$, or one collision out of 750 is effective in producing ionization. For sodium vapor at 365 deg C (vapor pressure = 0.15 mm of mercury, number of sodium atoms per cubic centimeter = 2.2×10^{15}) L. S. Ornstein and B. Baars[17] have deduced a value for L_e of 0.5 cm. From this they derive for the atomic radius the value $r = 1.7 \times 10^{-8}$ cm, and they conclude from measurements on the intensity of the D lines produced that at the maximum, 5 per cent of the collisions are effective in producing D-line radiation.

It should be noted that while $1/L$ gives the number of collisions per centimeter path, the actual direction between collisions is quite random and therefore the number of collisions per unit length in a given direction is $1/L^2$. An electron traveling a distance of one centimeter in neon at one millimeter pressure and 25 deg C makes $(12.7)^2 = 162$ collisions with neon atoms.

Life of Excited Atoms

(A very full discussion of the life of excited atoms, and related topics has been given by A. C. G. Mitchell and M. W. Zemansky, see reference 18.)

As has been mentioned previously, the intensity of a spectral line of frequency, ν_{kj}, corresponding to a transition from state k to state j, depends not only upon the probability of excitation from the lower to the upper state (P_e), but also upon the probability of occurrence of a transition from k to j. This probability is usually designated by A_{kj}, and the reciprocal, τ_{kj}, is a measure of the average life of the excited state k with respect to the radiation ν_{kj}.

16. K. T. Compton and I. Langmuir, *Rev. of Modern Physics*, v. 2, 1930, p. 208.
17. *Proc.* Amsterdam Acad. Sciences, v. 34, 1932, p. 1,259.
18. "Resonance Radiation and Excited Atoms," A. C. G. Mitchell and M. W. Zemansky. The Macmillan Company, 1934.

The physical significance of τ_{kj} may be stated thus: Given a certain number (n_0) of excited atoms in state k at $t = 0$, the number at the end of interval, t, providing that the rate of generation of excited atoms is zero, is given by

$$n = n_0\epsilon^{-t/\tau} \tag{15}$$

According to classical physics, the "damping factor," $1/\tau$, of a linear harmonic oscillator emitting radiation of frequency ν_0 (and wave length λ_0 in Ångström units) is given by the relation

$$\tau = \frac{3mc^3}{8\pi^2e^2\nu_0^2} = 1.131 \times 10^{-8}\left(\frac{\lambda_0}{5{,}000}\right)^2 \text{ sec} \tag{16}$$

where

c = velocity of light
m = mass of electron
e = charge on electron

On the other hand, the quantum theory point of view leads to a relation between the value of τ_{kj} and the absorption coefficient, α, of the resonance radiation of frequency, ν_{kj}. If I_0 designates the intensity of the radiation at $x = 0$, the intensity of the light passing through a thickness x of the absorbing atoms is given by

$$I = I_0\epsilon^{-\alpha x} \tag{17}$$

From measurements of α for any resonance radiation, the value of τ may be derived by means of a relation of the form

$$\alpha = \frac{K \cdot n \cdot \lambda_0^3}{\tau\sqrt{T}} \tag{18}$$

where K is a constant for the transition k to j; λ_0 is the wave length of the resonance line; n is the number of absorbing atoms per cubic centimeter, and T is the absolute temperature (in degrees Kelvin). Actually the absorption is observed for a radiation extending over an interval $\Delta\nu$ of frequencies, and the measurements give α as a function of ν over this range, so that the above relation applies strictly only to the center of the range which is at ν_0 (or λ_0).

The magnitude of the absorption for the resonance lines of sodium is evident from the measurements of W. Zehnden,[19] which are shown in Table IV. The relative intensity of the radiation after passing through a thickness of 1.492 cm of sodium vapor at the absolute temperature T is given under I/I_0. The last 2 columns give the values of α calculated by eq 17.

Table IV—Absorption for the Resonance Lines of Sodium

T	n	I/I_0 for D_1	I/I_0 for D_2	α_{D_1}	α_{D_2}
416.5	8.32×10^{10}	0.701	0.518	0.238	0.441
431.0	2.24×10^{11}	0.424	0.236	0.575	0.968
445.9	5.90×10^{11}	0.183	0.111	1.14	1.47

Extrapolation to $T = 503$, that is, 230 deg C, shows that at this temperature (at which $n = 1.25 \times 10^{13}$), the value of I/I_0 for the D_2 line decreases

19. *Zs. f. Phys.*, v. 86, 1933, p. 555.

to 0.1 in a distance $x = 0.74$ cm. The value of τ deduced from these measurements of α is 1.5×10^{-8} sec.

The absorption of mercury vapor for its resonance line λ2,537 is so great that, as R. W. Wood has shown, a shadow is cast by a quartz bulb filled with mercury vapor at room temperature (pressure = 0.001 mm, approximately) when illuminated by the resonance radiation. A depth of 0.5 mm of the vapor at 0.001 mm of mercury pressure reduces the intensity of a beam of resonance radiation to $^1/_3$ its initial value[20].

Just as atoms in the normal state absorb radiation of the frequency corresponding to the transition from the lowest excited state, metastable atoms may be excited to higher energy states by absorption of radiation. For instance, the metastable neon atoms in state s_5 (see Fig. 5) may be excited to one of the p-states by absorption of λ6,402, which is one of the most intense lines in the spectrum of the gas.

It is evident, as mentioned in a previous section, that the reciprocal of the absorption coefficient, that is, $1/\alpha$, may be regarded as the mean free path for the collision of light corpuscles (energy quanta or photons) with normal or excited atoms in the gas. Equation 17 shows that the magnitude $1/\alpha$ is a measure of the distance in which the light intensity is decreased to $1/\epsilon$ of its original value. Hence the light intensity is reduced to ϵ^{-2}, that is, to 0.135 of its original value in traveling a distance $2/\alpha$ and the number of collisions in that distance is 2α. In the case of the resonance radiation of sodium, $1/\alpha$ is equal to 0.32 for a pressure of sodium vapor of 0.00063 mm (at 230 deg C). Hence the resonance radiation originating at the center of a 2-cm diameter tube is absorbed and reëmitted 10 times before reaching the walls. Values of τ for the resonance lines of a number of atoms have been derived from observations on α and also by other methods. Table V shows some of the results obtained, and for comparison there are given in the last column, values of τ calculated by means of eq 16.

Table V—Average Life of Excited Atoms

Atom		λ in A	τ in Sec	τ (Calc.) in Sec
Lithium	(Li)	6,708	2.7×10^{-8}	2.04×10^{-8}
Sodium	(Na)	5,896, 5,890	1.48×10^{-8}	1.57×10^{-8}
Potassium	(K)	7,699, 7,665	2.7×10^{-8}	2.67×10^{-8}
Caesium	(Cs)	8,944	3.8×10^{-8}	3.62×10^{-8}
		8,521	3.3×10^{-8}	3.29×10^{-8}
Mercury	(Hg)	2,537	1.08×10^{-7}	2.91×10^{-9}
		1,849	1.30×10^{-9}	1.55×10^{-9}
Cadmium	(Cd)	3,261	2.5×10^{-6}	4.81×10^{-9}
		2,288	2.0×10^{-9}	2.37×10^{-9}

Cumulative Ionization

An atom in an excited state, B, may be raised to a still higher energy state, C, by 2 methods.

1. It may absorb radiation of wave number $\tilde{\nu}_B - \tilde{\nu}_C$ by a process similar to that by which absorbed resonance radiation brings about a transition from the normal to the first excited state—a process which has been discussed in the previous section.

2. The excited atom may collide with an electron from which it will receive the energy corresponding to $V_C - V_B$, where V_C and V_B are the excitation potentials of the 2 states. By successive impacts the atom may thus be excited to continuously increasing energy states until finally it becomes ionized.

This latter process of excitation and ionization by electrons in successive stages is designated as the *cumulative* type and plays an important rôle in all hot-cathode, low-voltage arcs, such as those in sodium vapor, neon, helium, or mercury vapor. It is possible, for instance, to obtain an arc in sodium vapor with a voltage drop slightly above 2.10 volts and below the actual ionization potential, 5.12 volts. Similarly arcs in mercury vapor may be obtained with a voltage drop less than 10.4.

Obviously the rate of cumulative ionization must increase with both the electron current density and the value of τ, for the longer the "life" of the excited state, the greater the probability of a collision between the atom in this state and an electron.

Since the rate of excitation by absorption of radiation according to process (1) also increases with electron current density and τ, a more detailed investigation is necessary to determine in any given discharge which of the 2 processes is more effective in causing ionization. According to a calculation carried out by K. T. Compton,[21,22] impact by photons is much more important in the case of arcs at low pressures.

Life of Metastable States

In a previous section mention has been made of the existence of metastable states in the case of all monatomic vapors and gases, except those of the alkali metals. By impact of electrons having the necessary kinetic energy, it is possible to excite mercury or neon atoms to these metastable states, but a transition from these states to the normal, which is accompanied by radiation corresponding in frequency to the energy difference involved, is extremely improbable. In fact, according to the older quantum theory, such transitions were "forbidden." But on the basis of the newer quantum mechanics, there does exist a definite probability, extremely small it is true, for such a transition, and this leads to values of τ for metastable states which are of a much larger order of magnitude than those for other excited states.

However, in a discharge, metastable atoms are actually destroyed in a much shorter interval of time, by one or more of the following processes, for each of which there is a high degree of probability of occurrence:

1. The metastable state may be excited to a higher energy state by the process of cumulative ionization.

2. The same result may be secured by absorption of radiation, as mentioned already. Thus in the case of neon, the atom in the metastable state s_5 can absorb λ6,143, λ6,402, or λ7,032. Similarly mercury in the $^3P_2$ state can absorb λ5,461 or λ3,663. In fact, observations on the intensity of absorption of the line λ6,402 have been used by various investigators to determine the concentration of metastable atoms in a neon discharge as well as the duration of existence of atoms in the metastable state.

20. "The Origin of Spectra," P. D. Foote and F. L. Mohler. The Chemical Catalog Company, New York, 1922.

21. *Phys. Rev.*, v. 20, 1922, p. 105.

22. "The Origin of Spectra." P. D. Foote and F. L. Mohler. The Chemical Catalog Company, New York, 1922.

3. An interesting and very important process by which the concentration of metastable atoms may be decreased is that designated as collisions of the second kind. This may be illustrated by referring to the energy level diagram for neon (Fig. 5) and Table II. The metastable state s_5 differs in energy from the resonance level, s_4, by only 0.05 volts. By collision with a neon atom, the atom in state s_5 may acquire sufficient energy to raise it to the state s_4. Similarly the metastable state s_3 may lose 0.04 volt by collision to from the state S_4. Under special conditions such collisions may also occur between ordinary excited atoms and electrons with the result that the kinetic energy of the latter is increased while the excited atom returns to a lower state without emission of energy. This is evidently the reverse process of that by which an electron transfers its kinetic energy to an atom (which is known as a collision of the first kind).

4. If there is present an admixed gas whose atoms have an ionization or excitation potential lower than that of the metastable atoms, the latter may transfer their energy to the former. For instance, in a mixture of neon and argon, the metastable neon atoms (V_m = 16.53 and 16.62) can bring about ionization of argon atoms (V_i = 15.69). Similarly in an argon-mercury mixture, metastable argon atoms may cause ionization of the mercury atoms.

5. Lastly, the metastable atoms are destroyed in a discharge tube by impact on the walls and other surfaces, where they cause emission of secondary electrons. The significance of this phenomenon in a neon discharge has been studied by a number of investigators.[23, 24]

Thus, in actual discharges the life of a metastable atom depends upon the conditions of temperature, pressure, current density, and diameter of tube. Under these conditions it has been found that τ may be expressed in terms of p, the pressure, by a relation of the form

$$\frac{1}{\tau} = \frac{A}{p} + Bp$$

where A and B are constants. The term A/p takes into account the rate of diffusion to the walls, while Bp gives rate of disappearance in the gas volume itself.

While values of τ as high as 0.1 sec have been observed for metastable states, the values obtained in usual type of discharges range from 10^{-2} to 10^{-4} sec at pressures of a few millimeters of mercury and ordinary temperatures. At very low temperatures the value of τ is increased. With increase in pressure from very low values, the value of τ increases at first, and then passes through a maximum beyond which further increase in pressure causes a decrease in τ.[25]

Thermal Excitation and Ionization

The production of spectra in stars is evidence of the excitation and ionization of atoms produced at high temperatures. At these temperatures there exists an equilibrium between the rates of excitation and ionization on the one hand and the rates at which both transitions to lower energy levels and recombinations occur. The relative distribution of atoms in 2 excited states A and B is then given by the Boltzmann relation

$$\frac{n_A}{n_B} = \frac{g_A}{g_B} \cdot \frac{\epsilon^{-V_A e/kT}}{\epsilon^{-V_B e/kT}} = \frac{g_A}{g_B} \epsilon^{-(V_A - V_B)e/kT} \qquad (19)$$

23. C. G. Found and I. Langmuir, *Phys. Rev.*, v. 39, 1932, p. 237.
24. C. Kenty, *Phys. Rev.*, v. 43, 1933, p. 181.
25. J. M. Anderson. *Can. Jl. Res.*, v. 2, 1930, p. 13; v. 4, 1931, p. 312; v. 7, 1932, p. 434.

where

n_A = number of atoms per cubic centimeter in state A
g_A = "statistical weight" of state A
V_A = excitation potential of state A
with similar meanings for n_B, g_B, and V_B
T = absolute temperature of gas
k = Boltzmann gas constant

As an illustration of the significance of this relation, consider the case of sodium vapor. For the normal state, which will be designated by A, g_A = 1; and for the first excited state, B, g_B = 2. Also $V_B - V_A$ = 2.10 volts. Since e/k = 11,600 deg per volt,

$$n_{Na'}/n_{Na} = 2\epsilon^{-\frac{24,360}{T}} \qquad (20)$$

where Na' denotes excited atoms in the $3P$ state.

Thus at T = 4,872 deg K, the ratio of excited to normal atoms is 0.0134, or 1.3 per cent of the atoms are in the first excited state.

On the basis of the Boltzmann distribution law, as stated in eq 19, Saha derived an equation for the degree of ionization as a function of the temperature. Denoting the concentration of normal atoms by n_a, that of singly charged positive ions by n_p, and that of electrons by n_e, Saha's equation has the form[26,27,28]

$$\log_{10} \frac{n_e n_p}{n_a} = \frac{5,040 V_i}{T} + \frac{3}{2} \log_{10} T + 15.385 \qquad (21)$$

From eq 21 it follows that at any given temperature the degree of ionization is lower the greater V_i. Therefore it is expected that atoms of helium, neon, and argon would be found to be ionized only in the highest temperature stars, while the ionization of caesium would occur in comparatively cold stars.

Probably a considerable fraction of the light obtained from high pressure arcs (such as the flaming and open air type and the mercury arc at high pressure) is due to thermal excitation and ionization followed by transitions to lower levels and recombination. In low pressure discharges the gas is not in thermal equilibrium with electrons and ions and practically all the light is due to excited atoms. The recombination of ions and electrons occurs only on the walls and the energy thus evolved merely raises the temperature of the walls and contained gas to not over a couple of hundred degrees above room temperature.

However, as will be more fully discussed in Part II of this paper, the electrons and positive ions in a low pressure discharge are each characterized by a "temperature" which may range from 5,000 to 50,000 deg K, and even higher.

26. Equation 21 is given by K. T. Compton and I. Langmuir, *Rev. of Modern Physics*, v. 2, 1930, p. 135.
27. "Statistical Mechanics," R. C. Tolman. The Chemical Catalog Company, 1927, p. 147.
28. "The Origin of Spectra," P. D. Foote and F. L. Mohler. The Chemical Catalog Company, New York, 1922, Chap. VII.

The second and concluding part of this paper on "Low Pressure Gaseous Discharge Lamps" is scheduled for publication in the September 1934 issue of ELECTRICAL ENGINEERING. In the present issue, radiation processes are discussed, and in Part II, electrical conduction processes will be covered.

Insulator Surface and Radio Effects

Because of the rapid extension of police radio systems, and because both electric power lines and police cars occupy the highways, the problem of power line radio influence has acquired an added importance. Insulators coated with dirt, moisture, and hygroscopic salts have been found to cause radio disturbances at voltages much less than those for clean insulators.

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THE high voltage insulator is an essential part of overhead circuits for the transmission or distribution of electric power. The adequacy of such circuits is judged principally by their reliability, which in turn depends largely on the adequacy of the insulator selected. The factors that determine whether or not an insulator is satisfactory are durability, mechanical strength, ability to resist flashover under lightning, ability to resist flashover at the operating voltage when wet and dirty, and freedom from radio effects.

Because of the rapid extension of police radio and because both power lines and police cars occupy the highways, the question of power line radio influence has acquired an added importance that makes it necessary to be able to separate out the causes of such effects and to determine their relative importance.

Since the wet flashover of an insulator and the radio effect which an insulator may cause are both functions of its surface properties, it was thought that a study of such properties should be undertaken with a view of learning more about the mechanism by means of which an arc is or may be established over the wet and dirty surface of an insulator, and of the manner in which the disturbances that affect radio receiving sets may originate. The ultimate objective is an improvement in design, the establishment of economic limits of performance, or both. The authors have been engaged in such a study for nearly 2 years, the results of which are presented in this paper.

Full text of a paper recommended for publication by the A.I.E.E. committee on power transmission and distribution, and scheduled for discussion at the A.I.E.E. Pacific Coast convention, Salt Lake City, Utah, Sept. 3–7, 1934. Manuscript submitted May 28, 1934; released for publication June 25, 1934. *Not published in pamphlet form.*

The wet arcover of an insulator starts as an arc between liquid electrodes; apparently a current of between 30 and 60 ma is required for this arc to be maintained until the gap between conductor and ground is bridged. Surface resistance must be small enough to permit this current to flow. Initiation of the arc is assisted by electrostatic forces which disrupt water drops and pull conducting material into the arc path. An insulator is most dangerous and most likely to flash over when the water film is thickest. Dirt, moisture, and hygroscopic salts on insulator surfaces increase leakage currents to a hundred or more times the dry value. The resistance drop in potential between conductor and surface film results in breakdown of the neighboring air and in radio disturbances at voltages far less than those at which breakdown would occur if this conducting film were not present.

Wet Arcover of Insulators

Properties of the atmosphere always are considered carefully by both the designer and user of an insulator. However, since wet flashover at operating voltage generally occurs during a fog, it was thought worth while to investigate the dielectric strength of fog laden air to see if it departs from normal and may be a cause of breakdown.

Sparking voltage-distance curves were determined for needle gaps on several different occasions for the dense sea fogs of central California. Observations were made on the summit of Twin Peaks in the western part of San Francisco, about 3 miles from the Pacific Ocean. In each test the curve corresponding to 100 per cent humidity was obtained, indicating that the dielectric strength of air under such conditions is a maximum, and of itself cannot be directly a cause of arcover. This is in agreement with other experimental evidence and with the accepted theory that the otherwise free ions in the atmosphere are trapped by fog and vapor particles and rendered less mobile, with the result that a higher voltage is necessary to cause breakdown.

Initiation of an Arc

A power arcover on a wet and dirty insulator starts as a weak low-current high-voltage arc, the current of which is limited by the ohmic resistance of the water film in series with it. Laboratory experience indicates that about 60 ma is the minimum current at which such an arc will not be blown out automatically. Therefore, for an insulator to be in a dangerous condition, it is necessary that the conductivity of the surface film, as influenced by both its thickness and the presence of dissolved conducting material, be at least sufficient to permit a current of 60 ma to flow. Such an arc also must start at a high resistance point on the insulator surface or between ribs, shells, or petticoats, and generally between boundaries of the water film. This means that the

arc terminal electrodes are liquid. To what extent the properties of such electrodes may affect the development of an arc is believed to be unknown. To shed some light on this question the following experiment was performed.

The sparking voltage-gap length curve at 60 cycles was determined for an air-gap between 2 horizontal brass strips approximately $^1/_8$ in. thick and 1 in. wide. This same curve then was determined immediately for liquid electrodes of the same dimensions. Liquid electrodes were established by placing thick water films on glass after the manner indicated in Fig. 1. The 2 curves obtained are shown in Fig. 2; they are believed to be significant. In performing this experiment it was discovered immediately that when the voltage is high enough (for these tests about 30 kv) the liquid film at its boundaries is disrupted by electrostatic forces, with the result that conducting material is sprayed into the gap. Beyond this point arcover takes place with a relatively small increase in voltage for increasing gap length. Up to this point the arcover voltage for both liquid and solid electrodes is approximately the same. Further work will include the study of solutions containing materials that lower the surface tension, which should result in arcover taking place at correspondingly lower voltages.

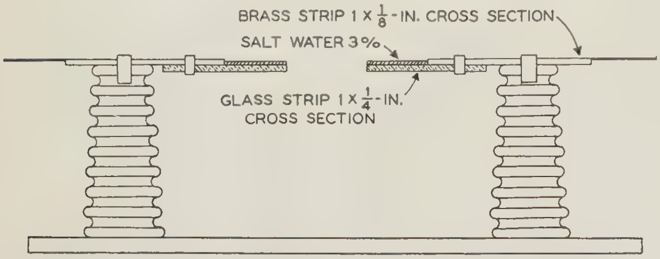


Fig. 1. Arrangement of liquid electrodes

In observing the flashover of a dripping wet suspension insulator the function of water drops as point dischargers is strikingly evident. By allowing a single drop of salt water to roll off the top surface of such an insulator it is easily possible to reduce the arcover voltage by 30 per cent less than that obtained in the standard A.I.E.E. wet test.

As an insulator becomes wet in an approaching fog, there is first a complete redistribution of voltage with the appearance of highly overstressed zones which "spit" vigorously. This is the period of nervousness for an observer but of safety for the insulator because the surface resistance is still too high to permit the development of an arc. As moisture is accumulated the insulator quiets down and may become entirely black with no electrical overstress. Its condition now is dangerous because the surface resistance is low enough to permit the development of an arc, once started.

On a foggy night hot yellow arcs have been observed to flash from a suspension insulator string that was perfectly black and showed no evidence of overstress, travel half the length of the string, and blow out. One of the authors was fortunate enough to observe the flashover in service of a large 4-part bus insulator operated at a line voltage of approximately 66,000 kv, or not more than 38 kv to ground. The nominal wet flashover voltage of this insulator under A.I.E.E. test conditions would have been at least 130 kv. Flashover occurred during a heavy fog when everything was dripping wet. The insulator itself was perfectly dark and showed no sign of overstress, but arced suddenly and without any warning whatsoever.

In summary, it is believed that the flashover of a wet and dirty insulator starts as a weak high-voltage arc, generally between liquid electrodes. The current is limited by the resistance of the surface film, but the disruption of this film at some point by electrostatic forces probably facilitates the initiation of the arc. An insulator is believed to be most dangerous when completely wet and showing no sign of overstress.

Radio Influence

It is a matter of common knowledge that, under certain circumstances, electric power lines may radiate electromagnetic waves that affect radio broadcast reception. The source of such radiation is generally the partial failure of a dielectric, whether it be air, oil, or solid insulation, resulting in a disruptive static discharge. This discharge may occur as corona into the air from conductor and fittings, through oil, through the cracked shell of an insulator, or through partially punctured coil insulation, about the conductor of a dry type bushing, from the cap lips, clevis bolt, or cotter key of a suspension insulator to the shell of the unit above it, as corona about the wire or pin of a pin type insulator, across loose joints in the hardware of wood construction, or over the surface of a dirty insulator in humid weather.

Circuits involved in generating this disturbance are indicated schematically in Fig. 3, in which R is the line impedance, C line capacitance, and C_1, C_2, C_3 the successive portions of a series of dielectrics. Upon the breakdown of C_1, represented by the discharge of gap g, capacitance C immediately discharges into capacitances C_2 and C_3 in series, resulting in a sudden change in the electric field that is propagated as an electromagnetic wave.

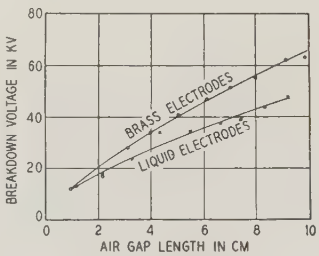


Fig. 2. Air gap-voltage curves for metal and liquid electrodes of similar dimensions

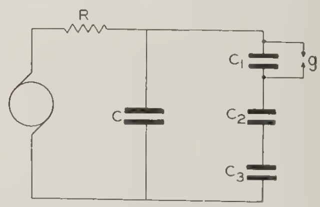


Fig. 3. Schematic representation of the generation of electromagnetic radiations that cause radio effects

Experience indicates that, in general, corona into the air will cause very little radio effect, because the

breakdown is gradual, not of the type indicated in Fig. 3, and the rate of energy transfer is small.

Referring again to Fig. 3, if capacitances C_2 and C_3 be shunted by a resistance, the value of which is low in comparison with the impedance of the capacitances, a disproportionate voltage will be thrown upon capacitance C_1 and gap g with the result that the gap will break down at a much lower voltage than if the shunting resistance of capacitances C_2 and C_3 were absent.

In practice, such a condition exists when the surface of an insulator becomes coated with a conducting film. The resistance of this film corresponds to a resistance that has been assumed to be shunting capacitances C_2 and C_3. Capacitance C_1 is represented by the electrostatic capacitance between insulator cap or tie wire and the surface film. A pin type insulator therefore should exhibit corona at the tie wire at a much lower voltage when its surface is coated with a conducting film than when it is not so coated.

Laboratory Experiments

In order to establish the truth or falsity of this conclusion, experiments were performed on glass plates to which were applied electrodes of conventional forms. Insulators near the sea coast were washed, and the wash water carefully was saved and applied to the glass surface so as to deposit thereon the same amount of solid material per unit of area as was found on the insulator.

Since the breakdown over an insulator surface as a cause of radio effect is the subject being studied, the performance of the film coated surface was compared with that of the clean surface by applying voltage to the electrodes and passing the combined leakage and charging current through the primary of a radio frequency transformer, the secondary of which was connected to the antenna circuit of a

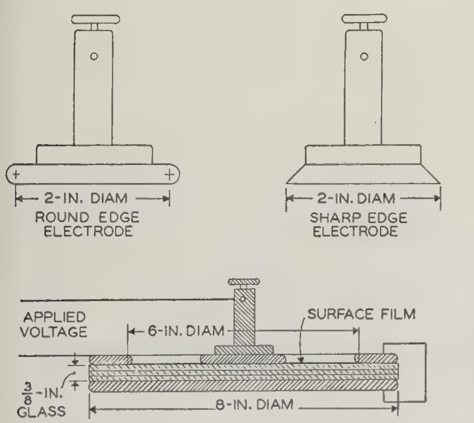


Fig. 4. Inner electrodes (above) and electrode assembly (below) used in laboratory tests

radio receiving set. The conductivity of the surface film is almost wholly dependent upon the amount of absorbed water, which in turn depends upon vapor tension and atmospheric humidity. Therefore, all tests were performed on both the clean and coated plates enclosed in a box wherein the humidity could be controlled within fairly close limits.

The test specimen consisted of a stack of 3 $^1/_8$-in. glass plates with conventional electrodes on opposite sides. The bottom electrode was a round brass plate, the top one a 2-in. brass disk in the center of a 6-in. annular ring. Electrodes used and their assembly are shown in Fig. 4.

The purpose of the annular ring was to provide a definite path, uniform in all directions, for leakage currents. For one series of tests, the glass surface

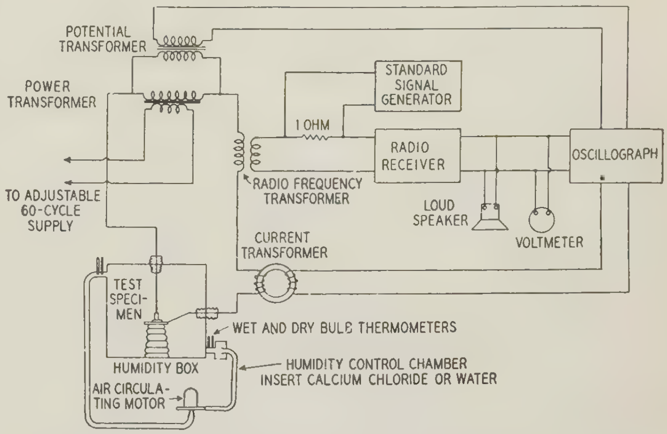


Fig. 5. Schematic diagram showing arrangement of equipment for laboratory tests

between the central electrode and annular ring was covered with wash water from dirty insulators taken from a line near the sea coast, so that, when dried, it would have exactly the same quantity of dirt and other material per unit of area as the average for the insulator surfaces in the field. The surface coating of these insulators was analyzed in terms of insoluble, incombustible material, which means sand and clay, and of chloride ion. The relative occurrence of these is: 1.0 milligram of dirt per square inch of surface, and 0.035 milligram of chloride ion. All of the material present on the insulator surface was transferred in proper amount to the glass surface. This gave the opportunity, by making observations with clean and dirty plates, of determining the effect of dirt and salt on the energy of the radio effect and on the voltage at which breakdown occurs.

The electrostatic capacitance of the electrode assembly with 3 $^1/_8$-in. glass plates is 25 $\mu\mu$f. This is about double that of a standard pin type insulator between the pin as one electrode and conductor and tie wire as the other, so that initial corona for clean surfaces should occur at a lower voltage than for an insulator.

Arrangement of apparatus for these tests is shown schematically in Fig. 5, and a photograph of the actual laboratory set-up in Fig. 6. The humidity control box was cubical, 3 ft on a side, and completely air tight. The air was circulated through an external pipe 3 in. in diameter by a small motor driven fan. The air entering the humidity box was forced through the control chamber in which a wire basket containing lumps of calcium chloride for drying the air could be inserted. Another basket, containing damp rags suspended in water replaced the calcium chloride basket when high relative

humidities were desired. The relative humidity in the box was determined by wet and dry bulb thermometer readings from thermometers inserted in the air pipes at the entrance to and the exit from the box. With this arrangement, relative humidities of from about 20 to 95 per cent are easily obtainable.

The transformer used was a 440/2,400-volt 3-kva power transformer. The power supply was a 220-volt line, which was connected to the transformer through a $1^{1}/_{2}$-kva induction regulator. The high voltage was introduced into the box through bushings in the side and top.

The radio pick-up coil was a radio frequency transformer, the primary of which was inserted in series between the power transformer and the specimen. The secondary of the coil was designed to have the same inductance as the loop antenna used in field observations in order that the same radio set could be used for the laboratory tests that was used in field observations. The output circuit of the radio and the oscillograph used were the same in the field tests.

This method of testing for radio effect caused by dielectric breakdown, so far as the writers know, was originated by Prof. F. O. McMillan (Oregon State College, Corvallis) and Mr. R. J. C. Wood (Southern California Edison Company, Los Angeles).

The test procedure consisted in establishing a desired humidity, then applying voltage to the test specimen, measuring the input to the radio set as in the field tests, and taking oscillograms. Surface resistance also was determined with a megger.

Results are given in the oscillograms, in the curve of Fig. 7, which shows the relation between relative humidity and radio effect for the dirty surfaces, and in Tables I and II. A striking difference between the performances of clean and dirty surfaces is illustrated clearly in the observations recorded in Table II.

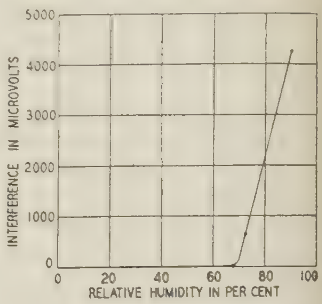
Fig. 6. Laboratory apparatus

Field Measurements

Field measurements of radio influence which, as will be shown later, are correlated closely with the laboratory tests, were made at Muir Beach, Calif., from a tap of the 11-kv Alto-Bolinas circuit of the Pacific Gas and Electric Company. This particular circuit was selected because of its isolation and freedom from many possible sources of disturbance; because at its operating voltage pin-hole and tie-wire corona would be absent if insulators were dry and clean; and because the insulators are exposed to a known type of contamination, salt spray from the ocean. Results of these measurements are given in Table III. The data therein recorded show exactly the same variation of radio effect with humidity as was found in the laboratory tests. Hours are required for the effect of a change in humidity to become manifest so that the 12:15 reading of October 17 still shows some radio effect which entirely disappeared in the subsequent readings at 4:30 and 7:45.

Fig. 7. Effect of relative humidity on interference

Round edge electrodes; 2,500 volts applied



On November 26, insulators were washed by hand. The 12:10 reading was taken immediately before washing. The readings of December 2 show the absence of radio effect with the clean insulators even though the humidity was comparatively high. The reading of May 10 was taken at another part of the line. The effect found at that station probably resulted from one or more cracked insulators. The reasons for believing this to be the case are given later.

Table I—Surface Resistance of Clean and Coated Glass

Surface Condition	Surface Resistance, Megohms	Relative Humidity, Per Cent	Center Electrode
Clean	100 +	91	Round edge
Coated, Muir Beach film	0.6	90	Round edge

Table II—The Results of Laboratory Tests on Clean and Coated Glass Surfaces

Surface Condition	Magnitude of Radio Effect, Microvolts	Relative Humidity, Per Cent	Center Electrode	Applied Volts
Coated, Muir Beach film	4,250	91	Round edge	2,500
Clean	0	91	Round edge	2,500
Clean	0	35	Round edge	2,500
Clean	0	29	Sharp edge	2,500
Clean	1,320	46	Sharp edge	7,000
Clean	1,160	85	Sharp edge	7,000

With respect to the magnitude of radio influence recorded in Table III, attention is called to the fact that the loop antenna used as a pick-up was within 25 ft of the 11-kv conductors and within 35 ft of the top

of the transformer pole. In order to obtain readings as large as possible the loop antenna was placed as near the source of disturbance as it was possible to get it.

It is a matter of common experience that power line disturbance diminishes in intensity at a high rate with distance from the line and it is rarely evident at distances greater than 300 ft. That was true in this case and was confirmed by repeated visits to the residences of nearby consumers connected to this circuit. Their receiving sets were much more sensitive than the one used in these measurements. At no time was the effect audible in their sets except when tuned to stations a thousand miles or more distant and then it was of the same order as static from the atmosphere.

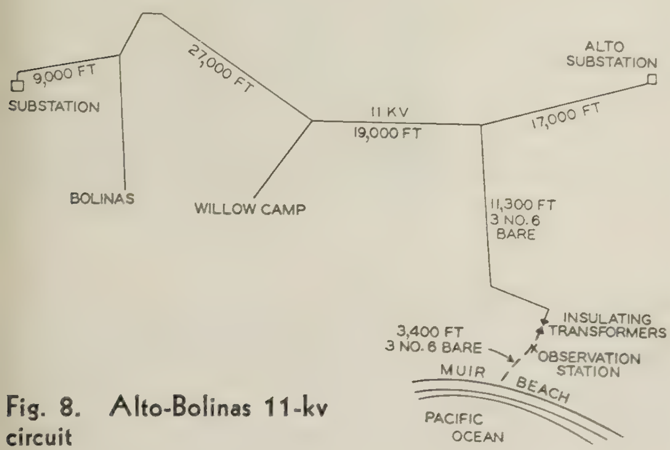


Fig. 8. Alto-Bolinas 11-kv circuit

Table III—Field Measurements of Radio Disturbance on the Muir Beach Tap Line

Date	Time (p.m.)	Magnitude of Radio Effect at Various Frequencies, Microvolts per Meter					Relative Humidity, Per Cent
		630 kc	720 kc	770 kc	840 kc	1,290 kc	
9-19-33	8:30	650	890	270	240	320	91
	10:00			400	330	410	
	11:00	470		300	430	400	
9-23-33	7:30	390		180		36	82
	8:55				180		88
9-24-33	6:20*	370		100	110	16	87
9-25-33	5:25	100	120	100	55	0	66
	6:25	220	190	250	200	170	100
	7:50	110	180	130	130	0	100
10-1-33	5:25	220	190	160	150	170	97
	9:30	320	280	330	240	150	
10-10-33	6:55	280	360	330	270	280	88
	8:15	320	430	430			
10-17-33	12:15	100	390	200	110	13	19
	4:30	0	0	0	0	0	
	7:45	0	0	0	0	0	65
10-24-33	12:37	57	110	130	240	2	88
	2:25	160	160	130	110	30	81
	3:55	280	160	170	110	120	83
	5:00	320	210	180	270	150	82
	3:30	160	210	120	130	70	90
	7:55	120	140	110	76		
11-6-33	2:30	45	96	830	0	0	82
	3:27	100	160	470	64	10	94
		200		200	70		
		120	280	93	61		
		89					
11-14-33	3:30	100	140	40	43	26	86
	4:25	180	280	110	70	70	
11-26-33	12:10	0	0	0	0	0	37
	5:00	0	0	0	0	0	63
	8:05	0	0	0	0	0	26
12-2-33	12:45	0	0	0	0	0	83
	1:30	0	0	0	0	0	80
	2:00	0	0	0	0	0	
	5:12	0	0	0	0	0	90
3-29-34	5:45	53	64	47	12	0	94
	7:05	77	140	40	12	0	
	9:00	16	71	43	0	0	
5-10-34	3:40		71	60		15	53

* a.m.

An interesting and altogether unexpected discovery is the fact that the radio effect was tuned very sharply at the 5 frequencies recorded in Table III. No explanation for this is offered. On other circuits sharp tuning also has been found, but in no other case within the authors' experience has the effect been limited to so few frequencies.

Had it been possible to continue the tests recorded in the curve of Fig. 7 to 100-per cent relative humidity, the curve would drop from a sharp peak suddenly to zero, for the reason that when the conducting film of moisture became heavy enough to function as a resistance without breakdown where it joins the electrode, all sudden current changes would cease and with them all radio effect. It is characteristic of power line radio influence caused by insulator surface breakdown resulting from dirt and moisture to increase with humidity, reach a maximum, and then decrease as insulator surfaces become thoroughly wetted. This was particularly true of the circuit observed at Muir Beach. In the latter stage, heavy power arcs would occur between shells or between petticoats of the same shell; but, although they occurred repeatedly at Muir Beach and were almost directly overhead, in no case did they cause any disturbance in the radio.

Yager (see "Electrical Leakage over Glass Surfaces," *Bell Laboratories Record*, v. 12, Oct. 1933) gives curves for adsorption on clean glass surfaces and for electrical conductivity that bear a strong resemblance to Fig. 7. He also calls attention to the time required for adsorption to take place. The same effect was observed with dirty film employed in the laboratory tests and in the field observations of October 17, Table III, previously referred to.

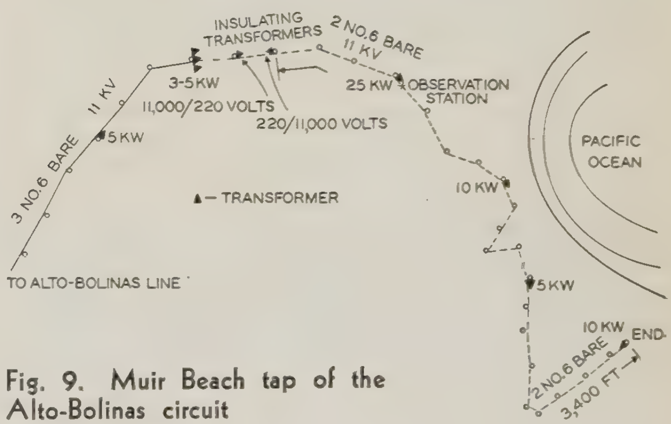


Fig. 9. Muir Beach tap of the Alto-Bolinas circuit

The influence of dirt in the form of finely divided clay or sand has not been determined, but is probably important as establishing points for electrical discharge to take place. On a clear night, with a light dew, 11-kv insulators along the sea coast have been observed to be faintly luminous, silhouetted against the sky by a line of pale blue light. Breakdown was occurring over the entire surface of these insulators at an average voltage gradient of not over 400 volts per inch, crest value.

Figs. 10 and 11. Observation station at Muir Beach

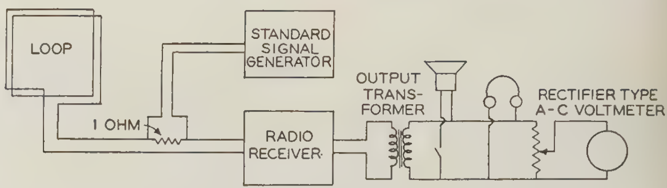


Fig. 12 (above). Arrangement of equipment used in the Muir Beach field tests

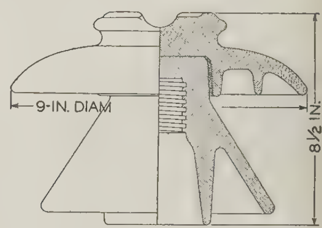


Fig. 13. Insulator used on the Muir Beach tap, 1933

Muir Beach Tap of the Alto-Bolinas Line

Location of the line and of the section used for test and observation at Muir Beach are shown in Figs. 8 and 9; Fig. 10 shows construction typical of the line. Important data are:

Voltage	11 kv, single phase, 60 cycles
Length of isolated section	3,400 ft
Number of poles	22
Pin type insulators (Fig. 13)	95
Transformer cut-outs	8
Suspension insulators in dead-end position	48
Transformers	4
High voltage transformer bushings	8

As indicated on the map, the line is near the sea coast, at a distance from it varying from 300 yards to $^1/_2$ mile. As shown in Fig. 9, the test section was a single-phase line and electrically isolated from the rest of the circuit by 2 transformers stepping the voltage down from 11,000 to 220 and back again. The purpose of this transformation was to exclude, if possible, the disturbances that otherwise might have been carried into this section by conduction from other parts of the circuit. Their efficacy in this respect was not determined.

Test Methods and Equipment Used in the Muir Beach Observations

The observation station was directly under the 11-kv line and about 20 ft west of the base of the transformer pole (see Fig. 9). The 2 11-kv wires were about 20 ft overhead. Figures 10 and 11 show the observation station.

The pick-up was a loop antenna which fed directly into a Radiola model 25 receiving set which had been completely shielded. The loop was tuned with a variable air condenser in the radio set. In series with one side of the loop was a 1-ohm resistance across which the output voltage of a standard signal generator could be impressed. The output of the receiving set fed into a speaker transformer. Across the output side of the speaker transformer was a speaker, a head-set, and a rectifier type of alternating current voltmeter. A switch in the speaker circuit was included for shutting off the speaker in making measurements of low interference levels. A potentiometer was used across the output transformer to vary the sensitivity of the output meter. A schematic diagram showing the arrangement of the equipment is shown in Fig. 12.

The Radiola model 25 is a 6-tube superheterodyne, using dry cell batteries which were incorporated within the shielded box. It has 2 tuning dials, one for tuning the loop, the other for tuning the oscillator. In addition, it has a volume control and a filament voltage control.

The standard signal generator consists essentially of 3 parts: an oscillator, an output meter, and a calibrated attenuator. The oscillator is tuned by a variable air condenser and modulated 30 per cent at 400 cycles per second. The output of the oscillator is measured by a thermal microammeter; the measured output then was attenuated by a calibrated attenuator.

The following procedure was used in making a measurement of the radio influence level: The radio set was tuned to the disturbance and the volume control adjusted to give a convenient deflection on the output voltmeter, the loop antenna being turned for maximum pick-up. The loop antenna then was rotated about 90 deg to zero pick-up. The signal

generator then was turned on and tuned to the frequency of the radio set. The output of the signal generator was adjusted to give the same deflection of the output meter as was caused by the radio disturbance, and the output and attenuation factor of the signal generator was recorded.

When the foregoing procedure had been completed, the microvolts induced in the loop antenna by the radio disturbance were equal to the microvolts inserted in the loop circuit by the signal generator, modulated 30 per cent at 400 cycles per second. The 1-ohm resistance in the loop circuit, across which the output voltage of the signal generator was applied, gave an additional attenuation factor of 10 for the signal generator output which was duly considered in the computations.

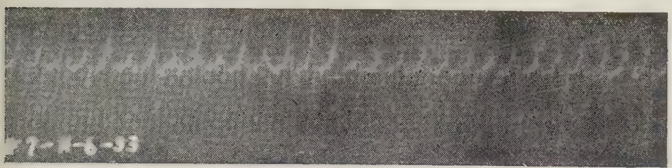


Fig. 14. Oscillogram of power line radio disturbance at Muir Beach as recorded at the output of the radio receiver

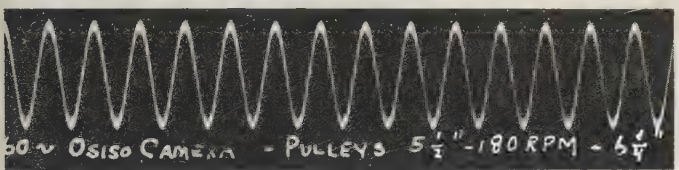
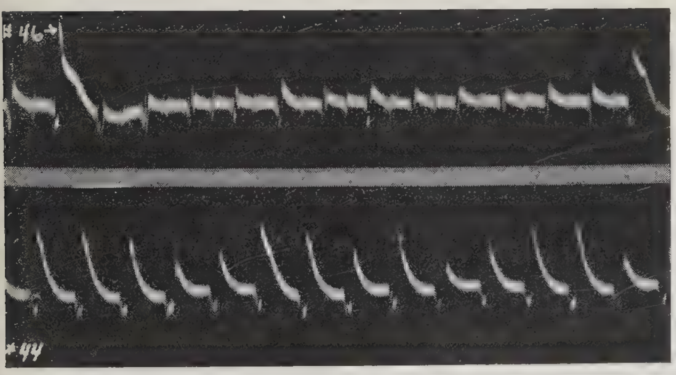


Fig. 15. 60-cycle timing wave for Figs. 14, 16, and 17



Figs. 16 and 17. Oscillograms of output of radio receiver obtained in the laboratory with coated glass surface and rounded inner electrode; 2,500 volts applied

Lower oscillogram (Fig. 17) taken with half-wave rectified voltage; inner electrode positive

When the oscillograms were made in the field, the output transformer of the radio set was replaced by a different output transformer which matched the impedance of the output of the radio set to the input impedance of the oscillograph. The oscillograph used was an "Osiso." Panchromatic motion picture film was used in the camera, which was driven by a synchronous motor through a belt.

Analysis of Substances Found on Surfaces of Muir Beach Insulators

Selected insulators carefully were removed from the pole top by a lineman who handled the insulators with a clean cloth in order to avoid contamination from handling. An insulator was placed in a large thoroughly clean, enameled pan, and washed with distilled water, using a clean test tube brush for scrubbing the surface. The water used in washing the insulator had been tested previously for chloride. Two insulators were washed for each sample. Three samples collected on October 24, 1933 were tested first.

A large amount of insoluble material was found on the insulator surfaces. Each wash water sample was filtered carefully through weighed filter papers. The total amount of insoluble material per sample was determined by weighing the dried filter paper and its contents. The filter paper then was ignited and the combustible material, which was essentially organic matter, was burned out of the sample. The residue, consisting of inorganic or uncombustible material, was weighed.

The filtered wash water was analyzed quantitatively for chloride and magnesium. The chloride content was determined volumetrically using silver nitrate of known concentration and dichlorofluorescein indicator. A second method, used as a check,

Fig. 18. Oscillogram of output of radio receiver obtained in the laboratory with clean glass surface and sharp-edge inner electrode; 7,000 volts applied

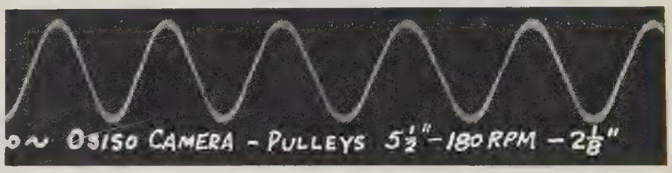


Fig. 19. 60-cycle timing wave for Figs. 18 and 20

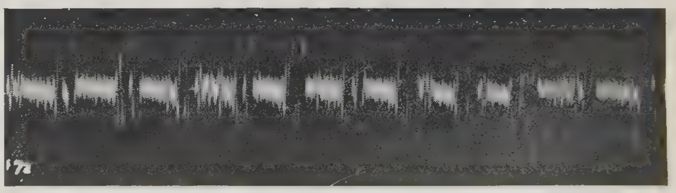


Fig. 20. Oscillogram of power line radio disturbance (output of radio receiver) at a point 10 miles from Muir Beach

consisted of adding excess silver nitrate and back-titrating with potassium thiocyanate using ferric alum as an indicator. The magnesium content was determined volumetrically using the 8-hydroxquinoline method.

The total insoluble material per insulator was found to be 0.41 g of which 0.07 g was organic matter and 0.34 g was inorganic. The chloride content per insulator was about 0.011 g and the magnesium content was found to be about 0.0024 g per insulator.

A second set of samples, collected March 17, 1934, was found to contain 0.0107 g of chloride per insulator and 0.0022 g of magnesium. The amount of insoluble material was not determined.

Discussion of Results

Laboratory and field tests seem to demonstrate conclusively that because of the heavy leakage current a coating of hygroscopic material on the surface of an insulator promotes, such a coating can cause an electrical breakdown at overstressed terminal electrodes at a voltage very much lower than that at which it would occur if this coating were not present.

On the Muir Beach insulators the hygroscopic material was magnesium chloride. Analysis of the deposit showed a ratio of magnesium to chloride ion of 4 times that found in sea water, indicating a preferential tendency for the magnesium chloride to stick to the insulator surface. The most plausible explanation is that other salts, like sodium chloride, can dry out and blow away, whereas magnesium chloride, which never completely dries out, will remain adherent. It is possible also that the electric field and space charges play an important part in causing the magnesium chloride to stick.

Oscillograms were taken at all 5 frequencies at which radio influence was observed at Muir Beach; they are so nearly alike that only one, Fig. 14, is presented. Direction of time in Fig. 14 is opposite to that in all of the other oscillograms. The 60-cycle

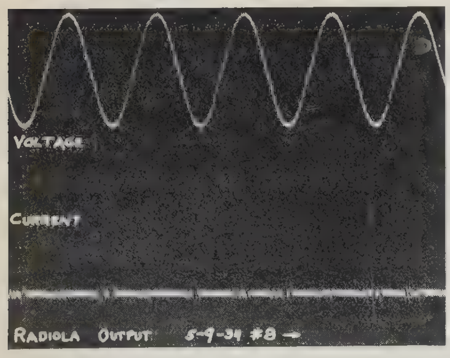


Fig. 21. Oscillograms obtained in the laboratory for clean glass surface and sharp-edge inner electrode; 5,800 volts applied

oscillograms establish time intervals. In only the oscillograms of Figs. 21 and 22 were 60-cycle wave forms taken simultaneously with those of the audio-requency output of the radio set.

That the radio effect established in the laboratory and that measured in the field were ascribable to the same cause would seem to be established by the humidity-intensity relationship and by the marked similarity of the oscillograms shown in Figs. 14, 16, and 17.

Breakdown, when it occurs, takes place with equal suddenness, whether the insulator surface be coated or not; the only effect of the coating is to make it occur at a lower voltage. This is indicated by the similarity of the audio-frequency output in the oscillograms of Figs. 18 and 22. Figure 18 is for sharp-edged inner electrode on clean glass with 7,000 volts applied; Fig. 22 for rounded inner electrode on coated glass with 2,500 volts applied. The polarity effect is marked. Tests with a kenotron and half wave rectification indicate that the pronounced breakdown shown in Fig. 22 occurs when the inner electrode is positive.

Leakage current with coated plate is shown in Fig. 22, while Fig. 21 shows the charging current with a clean plate. In both cases the current rush at breakdown is so small as generally not to be recorded; this means that it must occur with extreme suddenness. The current recorded in Fig. 21 was of the order of one milliampere and required an element of maximum sensitivity, as did Fig. 22.

The oscillogram of Fig. 20 was taken under the Alto-Bolinas line about 10 miles from Muir Beach, on

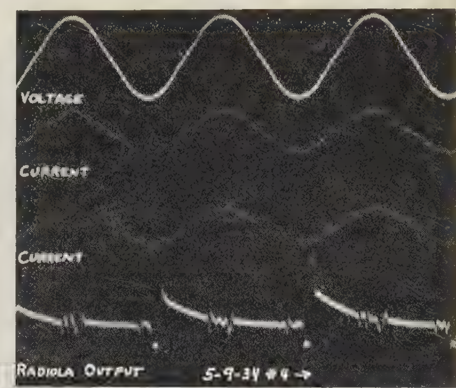


Fig. 22. Oscillograms obtained in the laboratory or coated glass surface and rounded inner electrode; 2,500 volts applied

May 10, 1934. It is quite different from the Muir Beach oscillograms of which No. 7 is typical, but similar to what the radio set output of Fig. 21 would have been if amplified. Since Fig. 21 gives the breakdown over a clean surface, the inference is that the disturbance recorded in Fig. 20 was caused by a cracked insulator. The Muir Beach insulators were all new, whereas only a short span length from where the oscillogram of Fig. 20 was taken were suspension insulators known to be more than 20 years old.

Testimony of operating men and a survey of power line radio effects covering half the state of California and circuits at all voltages from 11 to 220 kv, indicate that dirt, soluble salts, and humidity are among the principal factors causing power line radio influence in this territory.

Corona into the air seems to cause little disturbance. The breakdown is gradual, the rate of energy transfer slow, and there is no sudden charge or discharge as of a capacitor.

As to remedy, one, long known and expensive, is to keep insulators clean. Some of the protected or low capacity types of insulators recently brought on the market may be of value.

The Insulator String

A series of tests on suspension insulators for power transmission lines is described in this paper, and results are given which should be of interest to design engineers. The tests made included long-time fatigue tests, the distribution of voltage over the insulator string, and the flashover voltage when some of the units are electrically defective.

By
R. W. SORENSEN
FELLOW A.I.E.E.

Calif. Institute of Technology, Pasadena

THE insulator string as used on power transmission lines has been chosen for discussion because any progress made in standardizing the insulator unit itself, the number of units per string for any given voltage, and the supplementary appurtenances used in connection with them on transmission lines will be of value to engineers responsible for the design of such lines.

As an example of the need for some agreement on these points, consider a 230-kv transmission line, several of which have been built and operated for a number of years. Apparently agreement is found on one point only; namely, suspension insulators will be used. Also, it is found that the 10-in. insulator with a distance spacing along the string of $5^3/_4$ in. is the popular unit.

With this discussion limited to the insulator string and the units which comprise it, the features which determine the selection of the unit will first be considered. A.I.E.E. Standards No. 41 prescribe certain tests which enable the determination of the relative ability of insulators to render service. The tests prescribed, however, cannot tell the whole story, because such factors as the relation between short time mechanical loading tests and long time mechanical loading service, the number of units per string and the desirable distance spacing per unit along the string do not come within the scope of these rules.

This paper presents the results of some long-time fatigue tests on 10-in. insulators, and tests showing the voltage distribution and the flashover voltage for insulator strings made up of these units when there are electrically defective units in the string.

Full text of a paper recommended for publication by the A.I.E.E. committee on power transmission and distribution, and scheduled for discussion at the A.I.E.E. Pacific Coast convention Salt Lake City, Utah, Sept. 3–7, 1934. Manuscript submitted June 11, 1934; released for publication June 25, 1934. *Not published in pamphlet form.*

Inconsistencies Shown in Practice

An examination of the design data for various 230-kv transmission lines which have been built discloses the fact that insulator strings varying from 11 units per string to 18 units per string with conductor spacing varying from 17 ft 6 in. between conductors to 28 ft between conductors, are used. With full allowance made for all the variations in operating conditions, if 11 and 12 insulator units per string and 17 ft 6 in. spacing are satisfactory, as seems to be the case, on the original Big Creek lines, one naturally is somewhat puzzled to understand why other lines need 18 units per string with the consequent large spacing between conductors and the heavier towers required for strings of such length.

Apparatus for Long-Time Fatigue Tests

The long-time fatigue tests were made with the apparatus shown in Fig. 1. (For a description of the apparatus, see "Insulator Research," by R. J. C. Wood, N.E.L.A. *Proc.*, v. 83, 1926, p. 963–8.)

The apparatus is so constructed that one set of weights loads 2 strings, thus making the loading of one string of a pair dependent upon that of the other. The design is such that the 2 strings have different loading; hence, when the string with the greater pull is adjusted to give a certain rate of failure on the units, the rate of failure on the units of the other string will be lower. This is a good arrangement in that it furnishes a check regarding the tension to be used to get a satisfactory rate of failure.

Four strings of 20 units each can be set up in the apparatus at one time and each of the strings, for the tests being described, comprises 5 groups of insulators, each group consisting of 4 identical units. At the start of the test 16 units were selected at random from samples submitted by each manufacturer, these 16 units being divided into 4 groups of 4 units each, one of the groups being placed in each of the test strings. The weights at the end of the lever arms were then adjusted to give the tensions shown in the load-time test graphs of Figs. 2–5. These figures show the load in pounds on the string and number of days the load was applied to the particular string which the figure represents, and the time of failure for each of the units. It is intended to continue the test until all the insulators, 16 of each make, are tested to failure, either electrical or mechanical.

Definitions of Failure

The term electrical failure as applied to these tests is used to designate the fact that the insulator will no longer stand a flashover test, but breaks down by puncture when voltage is applied. A flashover voltage test was applied to every unit at the start of the test and whenever any change was made in the

string. Also the electrical integrity of every unit on the test was determined at such intervals as seemed desirable by the application of sufficient voltage to cause flashover. Thus, while the voltage was not applied continuously, it was applied at least once each day and at times when the rate of failures was high, the flashover test was applied several times per day.

The term mechanical failure means a failure of the insulator such as would drop the line conductor. All the mechanical failures did not involve electrical failure because in some cases the cap pulled off the porcelain or the pin pulled out without causing a fracture through the body of the insulator.

Replacement of Insulators on Test

Whenever an insulator failed electrically or mechanically it was replaced by a new unit and the test continued. This plan, of course, made it necessary to unload and reload again the remaining units of the string at each failure, a condition which may have shortened the life of some of the units of the string as compared to the life these same units would have had under a steady load. This feature, however, should not lessen the value of the

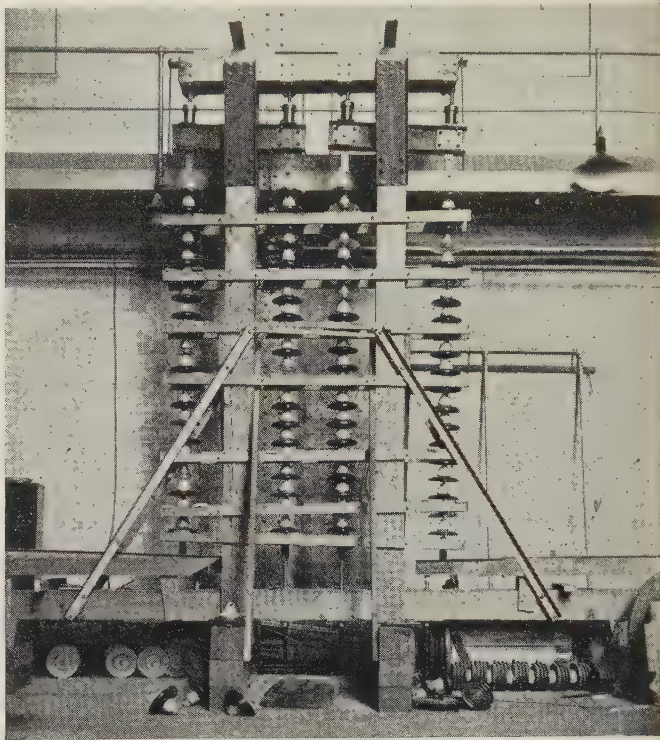
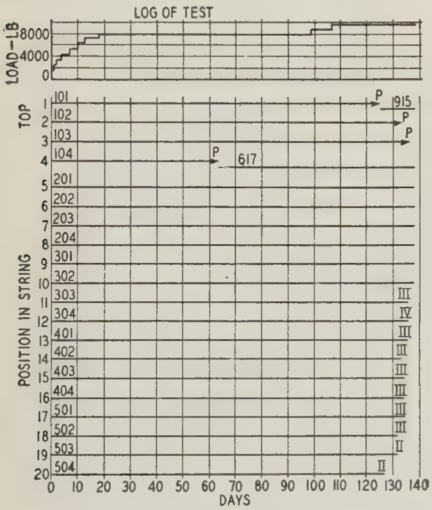


Fig. 1. Apparatus used in the long-time fatigue tests on suspension insulators



Numbers on horizontal lines identify the insulator unit

Arrows at end of lines show time of insulator failure

Dots show immediate failure when load was applied

P—Pin pulled
C—Cap pulled
S—Porcelain shear

Roman numerals show string to and from which insulator was transferred

Fig. 2. Results of tests on string I

Figs. 2–5. Long-time fatigue tests on insulators, showing load-time curves and time of failure of each unit of the insulator string

Length of line shows life of unit; *e. g.*, unit 101 on at beginning failed on 125th day; unit 915 on at 125th day, still good at end of record

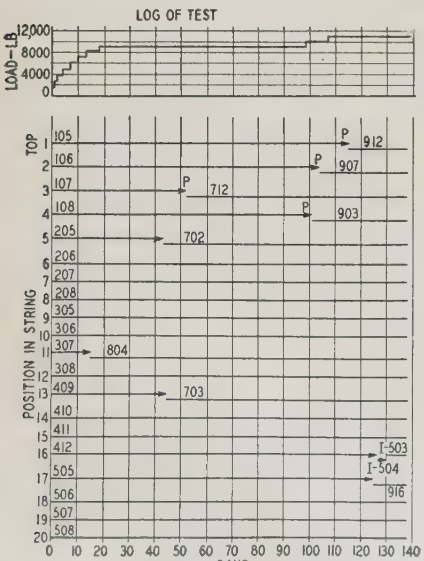


Fig. 3. Results of tests on string II

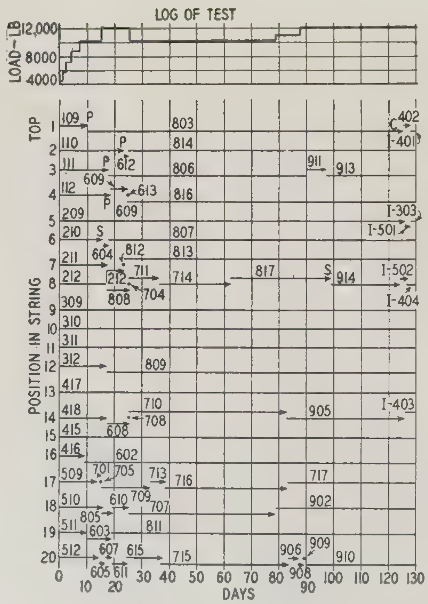


Fig. 4. Results of tests on string III

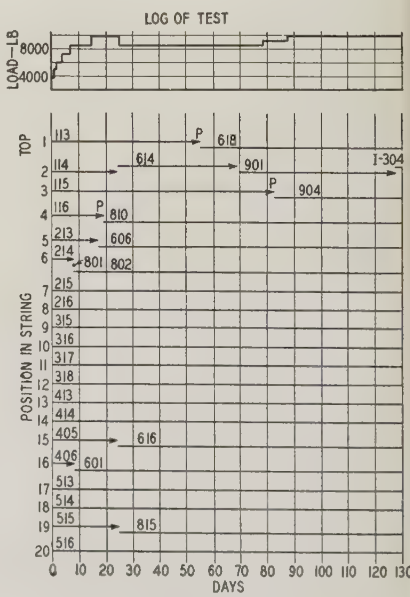


Fig. 5. Results of tests on string IV

ests because all units were subject so far as possible o identical conditions and in actual use on the line nsulators are certainly subject to changes in load, hough the changes are, of course, of lesser range. At all times the loading and unloading was done

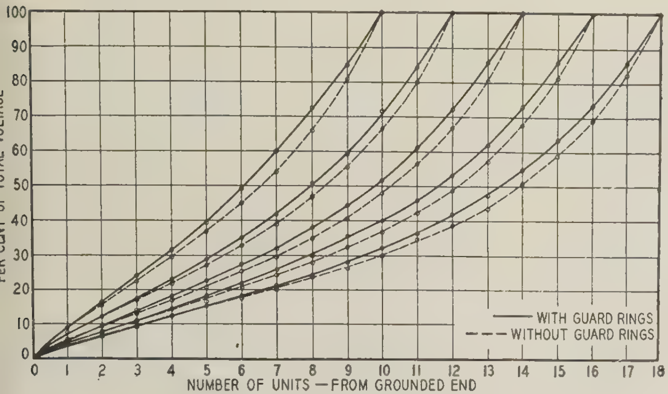


Fig. 6. Curves of voltage distribution on suspension insulator strings made up entirely of good units

slowly and great care was taken to avoid sudden shock to the units.

The apparatus is provided with dash pots to avoid shock when a unit in a string breaks.

Results of Fatigue Tests

In starting the tests, as shown by Figs. 2 to 5, small loads were applied to detect any weak units or damaged units and to provide opportunity for

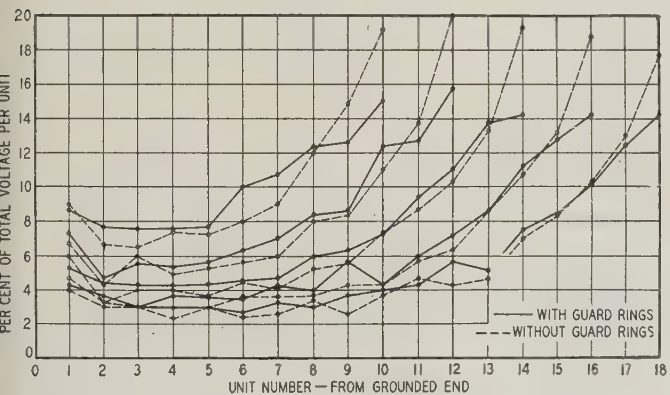


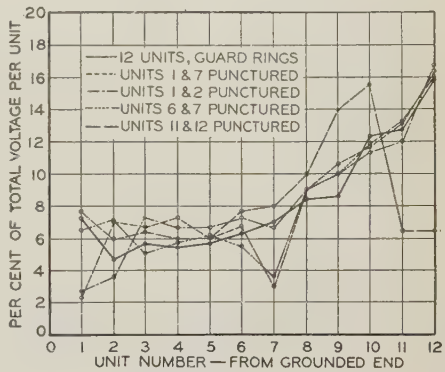
Fig. 7. Curves of voltage distribution on suspension insulator strings, using same data as in Fig. 6, but indicating the percentage of total voltage across each unit

perfecting the technique of testing before any failures could occur. It will be noted that the lowest tension at which any mechanical failure occurred was 8,000 lb and that there were several such failures as time went on at from 8,000 to 10,000 lb load, a condition of considerable concern to engineers responsible for lines located in places where sleet and wind loads approach these values.

There were also a few electrical failures on insulators at the lower mechanical load values, but these showed a greater division among the several lots tested and therefore may properly be charged to the inherent difficulty of obtaining a uniformity of product rather than to methods of assembly, the particular kind of material used in the insulator, or to the insulator design. (See "Testing Insulators to Assure Continuous Service" by R. W. Sorensen, *Elec. Wld.*, v. 70, 1917, p. 426–8.) Thus it may be said that while great progress has been made in the manufacture of porcelain, the material used most for insulators both as to maximum quality and uniformity, there still seems room for the development of technique in manufacture or perhaps change to materials yet to be found which will enable one to make a more uniform insulator.

There was only one mechanical failure of any porcelain insulator with caps and pins attached by

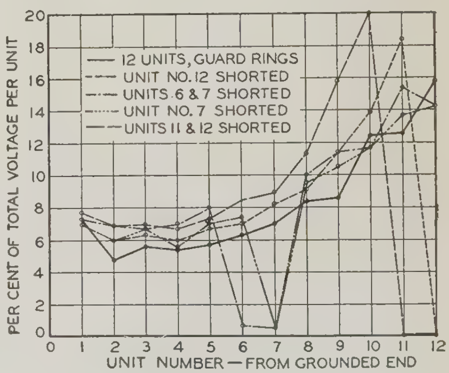
Fig. 8. Curves of voltage distribution across suspension insulator strings when there are electrically defective units in the string, drawn on the same basis as Fig. 7



cement. In this instance the cap pulled off the porcelain, a type of failure which must have been due to poor workmanship in applying the cement.

All the insulators used for these tests were specified as insulators capable of standing a pull of 15,000 lb or more on the short-time mechanical-electrical test. It is interesting to note that the life of those units which were rated for loads somewhat higher than 15,000 lb for the mechanical-electrical test did not show on the long-time test any great ad-

Fig. 9. Curves of voltage distribution across suspension insulator strings similar to those of Fig. 8, except each defective unit is shorted out



vantage over the others. The units tested which had the caps and pins attached to the insulating material by means of metal alloy rather than Portland cement did not give as good performance on the long time test as did the cemented units, and there

is some indication that on the long-time tests this metal tends to flow beyond the desired point of evening up the stress and thus causes a weakening of the insulator.

Distribution of Voltage Over the String

In addition to the mechanical tests on the insulator units, the study forming the basis of this paper includes an analysis of the distribution of voltage over the various units of the insulator string, particularly for strings in which there are damaged units.

Results of a few of the typical arrangements tested, are shown in Figs. 6 to 9. In Fig. 6 are shown distribution curves with and without guard rings for insulator strings made up entirely of good units. In Fig. 7 are shown curves using the same data but drawn in such a way as to show the percentage of total voltage across each unit of the string. In Fig. 8 is shown the percentage of the total voltage across each unit when there are electrically defective units in the string; that is, units which will not stand flashover voltage but will, when voltage is applied, permit current to discharge through the unit. It is interesting to note that the

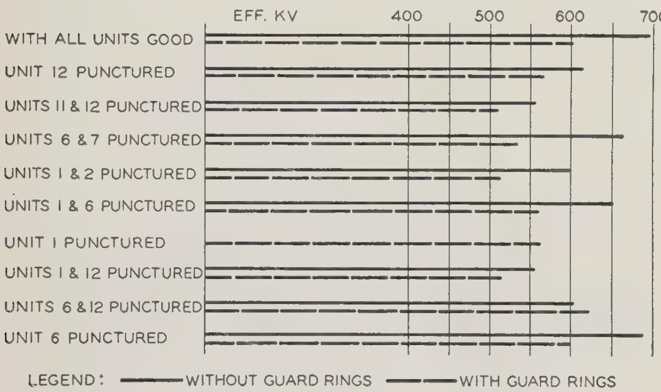


Fig. 10. Flashover voltages of 12-unit suspension insulator strings containing punctured units

voltage distribution is not badly disturbed by this condition. In Fig. 9 are shown curves similar to those of Fig. 8 for units shorted out by connecting the cap and pin of each defective unit together by a wire.

These tests were made on the hypothesis that from time to time during the operation of any transmission line there will be defective units in some of the insulator strings, thus making it highly desirable—in the consideration of lines which will not have the maximum factors of safety which one can purchase, but rather the minimum factor which will serve the purpose of the line—to know quite definitely the effect of defective units in different positions in the string. Not more than 2 defective units in each string were considered, because good practice in operation should permit the detection and replacement of defective units before more than 2 units per string have become defective.

Flashover Voltages

Flashover voltages under conditions noted for insulator strings in which some of the units are defective are shown in Figs. 10 and 11.

In addition to the flashover voltages shown by Figs. 10 and 11, flashover tests were made on a 15-unit insulator string which had been suspended for 5 months along the route of the transmission line under consideration in a region covered by a dry highly alkaline dust. The dry flashover test on this string was, as expected, the same as the dry flashover test of a clean 15-unit string; namely, 800 kv effective. When the string was sprayed with a very fine moisture spray the flashover test dropped to about half this value, which means that this

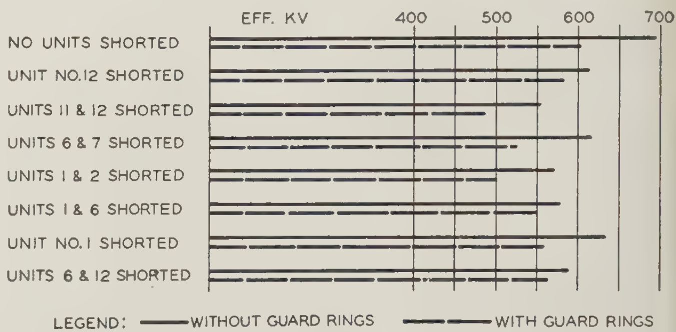


Fig. 11. Flashover voltages of 12-unit suspension insulator strings with certain units short-circuited

alkali dust wet with a fine spray to simulate a fog reduces the flashover voltage to 50 per cent of the dry flashover voltage for clean insulator strings; whereas the wet flashover voltage of clean insulator strings is about 70 per cent of that for clean dry strings.

Conclusions

The conclusions reached as a result of the tests described in this paper may be summarized as follows:

1. The short-time mechanical-electrical test does not determine the ability of the suspension insulators to maintain long-time high load stresses.

2. There has been much improvement in the suspension insulator during the past 15 years, but during the latter half of this period of improvement there has been little change except the addition of one make of glass insulator which ranks with the better ones of the group tested.

3. On the whole these tests indicate an apparent superiority of cement over metal as a means of attaching the hardware to the insulator.

4. Long-time mechanical tests, while somewhat troublesome, appear to have value and are recommended in making insulator selections.

5. One or 2 defective insulators in a 12-unit string do not change the voltage distribution along the string enough to overstress seriously any unit in the string.

6. Flashover tests show that defective units in an insulator string have little effect on flashover values unless the defective units are at the end of the string, in which case there is, of course, the expected reduction in equivalent string length.

News
Of Institute and Related Activities

50th Annual Summer Convention Held at Hot Springs, Va.

COMPLETING its first half century of technical and professional service, the American Institute of Electrical Engineers held its 50th annual summer convention during the week of June 25 at the Homestead Hotel, Hot Springs, Va. With but minor deviations, the program as previously published in ELECTRICAL ENGINEERING was followed out. In addition to the annual conference, the various technical sessions, and the regular meeting of the board of directors, numerous technical and other committee and subcommittee groups took advantage of the opportunity to hold informal meetings.

A feature of the convention, incident to the official recognition of the 50th anniversary, was the attendance of 9 past presidents of the Institute in addition to the president and president-elect, Charles F. Scott, 1902–03; Bion J. Arnold, 1903–04; Lewis B. Stillwell, 1909–10; Dugald C. Jackson, 1910–11; Paul M. Lincoln, 1914–15; Comfort A. Adams, 1918–19; Arthur W. Berresford, 1920–21; William McClellan, 1921–22; and H. P. Charlesworth, 1932–33. This is the fourth time in 14 years that the summer convention has been held in the South (District No. 4).

Annual Business Meeting

The opening session of the Institute's 50th annual summer convention was held Monday morning, and consisted of the annual business meeting, followed immediately by a 50th anniversary meeting. The annual business meeting was called to order by President J. B. Whitehead, who first introduced Prof. W. S. Rodman, chairman of the summer convention committee, who welcomed the members and guests at the convention.

The first item of business was the presentation by National Secretary H. H. Henline of a brief outline of the annual report of the board of directors, which indicates in general, improved conditions over those existent a year ago. The good work of the president and several of the more important committees was referred to, and the fact that the reserve capital fund upon which the Institute has depended for emergency has increased in value since a year ago was pointed out. (This report of the board of directors was published in full in ELECTRICAL ENGINEERING for July 1934, p. 1095–1107.)

REPORT OF THE COMMITTEE OF TELLERS

The report of the committee of tellers on the election of officers of the Institute was presented, and in accordance therewith President Whitehead declared the election of the following members, taking office August 1, 1934:

President: J. Allen Johnson, chief electrical engineer, Buffalo, Niagara & Eastern Power Corp., Buffalo, N. Y.

Vice Presidents:

W. H. Timbie, professor of electrical engineering and industrial practice, Massachusetts Institute of Technology, Cambridge, Mass.

R. H. Tapscott, vice president, New York Edison Company, New York, N. Y.

G. G. Post, vice president in charge of power, Milwaukee Electric Railway & Light Company, Milwaukee, Wis.

F. J. Meyer, vice president in charge of operation, Oklahoma Gas & Power Company, Oklahoma City, Okla.

F. O. McMillan, research professor of electrica engineering, Oregon State College, Corvallis, Ore.

Directors:

F. Malcolm Farmer, vice president and chief engineer, Electrical Testing Laboratories, New York, N. Y.

N. E. Funk, vice president in charge of engineering, Philadelphia Electric Company, Philadelphia, Pa.

H. B. Gear, assistant to vice president, Commonwealth Edison Company, Chicago, Ill.

National Treasurer:

W. I. Slichter, professor of electrical engineering, Columbia University, New York, N. Y.

The board of directors for the next administrative year, beginning August 1, 1934, will consist of these newly elected officers, together with the following hold-over officers: J. B. Whitehead (retiring president), Baltimore, Md.; H. P. Charlesworth, New York, N. Y.; R. B. Bonney, Denver, Colo.; F. M. Craft, Atlanta, Ga.; A. H. Hull, Toronto, Ont.; R. W. Sorensen, Pasadena, Calif.; A. M. Wilson, Cincinnati, Ohio; L. W. Chubb, East Pittsburgh, Pa.; B. D. Hull, Dallas, Tex.; P. B.

1934 Pacific Coast Convention Headquarters

TECHNICAL sessions and many of the entertainment features which will be a part of the Institute's 1934 Pacific Coast Convention, Sept. 3–7, will be held in the Hotel Utah, at Salt Lake City. Details of the technical sessions and an outline of some of the entertainment features were given in ELECTRICAL ENGINEERING for July 1934, p. 1128–9. A brief summary is given in an accompanying item in the present issue.

Among those prominent at the Institute's recent 50th annual summer convention, held at Hot Springs, Va., June 25–29, 1934, were those shown here. From left to right: W. S. Rodman, chairman of the general convention committee and dean of engineering at the University of Virginia, University; G. A. Kositzky, Cleveland, Ohio, and H. W. Eales, Chicago, Ill., who were respectively winner and runner-up in the Mershon golf trophy play; F. M. Craft, Atlanta, Ga., winner of the Lee golf trophy; R. B. Stewart, Washington, D. C., and E. F. Lopez, Mexico City, respectively runner-up and winner (second time) of the Mershon tennis trophy

Juhnke, Chicago, Ill.; G. A. Kositzky, Cleveland, Ohio; Everett S. Lee, Schenectady, N. Y.; A. H. Lovell, Ann Arbor, Mich.; L. W. W. Morrow, New York, N. Y.; A. C. Stevens, Schenectady, N. Y.; H. R. Woodrow, Brooklyn, N. Y.

INTRODUCTION OF THE PRESIDENT-ELECT

President Whitehead then presented the president's badge to President-Elect J. Allen Johnson. In his brief address of response, the incoming president stated in part ". . .perhaps you would like to know how it feels to be elected president of the American Institute. I think the first feeling is one of surprise that your fellow engineers have considered your accomplishments or services of sufficient value to be recognized, and then I would say there comes a feeling of pride and pleasure and warmth of spirit, and then that feeling is followed by a feeling of humility, wondering if you have the ability to meet the requirements of the job, and then that is followed by a spirit of resolution to do the best you can.

"Then I got to thinking, well, a resolution for what? Now of course, a resolution to carry on the spirit and the traditions of the Institute, but is that enough? And thinking it over, it seemed to me a little bit more than that was required, because we make progress as we prove all things and hold fast to that which is good, or as James Russell Lowell put it in his poem, 'The Crisis':

'New occasions teach new duties,
Time makes ancient good uncouth;
He must onward still, and upward
Who would keep abreast of truth.'

So I feel that in addition to keeping abreast or keeping up with the old traditions, we must have the courage in this changing world in which we find ourselves to try new things and find new goods and hold fast to those as well as to the old goods. And so it is my hope that I and we all of us in the coming year may find the courage or may not be lacking in the courage to try new things and hold fast to those which may prove to be new goods."

INSTITUTE PRIZES AWARDED

The report of the committee on award of Institute prizes, as published in ELECTRICAL ENGINEERING for June 1934, p. 1026, and in the present issue, p. 1234 was read by R. N. Conwell, chairman of the committee on award of Institute prizes, after which President Whitehead presented the certificates of award to those winners who were present.

PRESIDENTIAL ADDRESS

Another feature of the annual meeting was the presentation of the annual presidential address delivered by President Whitehead, wherein he outlined his most striking impressions of Institute activities which he had gained during his term as president. Essentially the full text of President Whitehead's address appears in this issue, p. 1143–5.

Lamme Medal for 1933

An impressive event on program of the annual business meeting was the formal presentation of the Institute's Lamme Gold Medal to DR. L. B. STILLWELL (A'93, M'92, F'12, member for life, and past president) consulting engineer of New York, N. Y. This medal was awarded him "for his distinguished career in connection with the design, installation, and operation of electrical machinery and equipment." Brief biographical sketches of Doctor Stillwell are given in ELECTRICAL ENGINEERING for March 1934, p. 503–4, and May 1934, p. 798.

OTHER AWARDS OF THE LAMME MEDAL

Previous awards of the A.I.E.E. Lamme Medal have been made to A. B. FIELD (A'03, F'13) consulting engineer, Manchester, England, 1928; R. E. HELLMUND (A'05, F'13) chief engineer, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., 1929; W. J. FOSTER (A'07, F'16) consulting engineer, retired, General Electric Company, Schenectady, N. Y., 1930; GUISEPPE FACCIOLI (A'04, F'12) deceased, January 13, 1934, formerly associate manager of the Pittsfield (Mass.) Works of the General Electric Company, 1931; and EDWARD WESTON (A'84, M'84, HM'33, member for life, and past president) chairman of the board, Weston Electrical Instrument Corporation, Newark, N. J.

The Institute's Lamme Medal was established by provision of the will of Benjamin Garver Lamme (deceased July 8, 1924)

Future AIEE Meetings

Pacific Coast Convention,
Salt Lake City, Utah, Sept. 3–7, 1934

Winter Convention,
New York, N. Y., Jan. 22–25, 1935

South West District Meeting,
Oklahoma City, Okla., Apr. 24–26, 1935

Summer Convention
Ithaca, N. Y., June 24–28, 1935

Pacific Coast Convention
Los Angeles vicinity, Fall 1935

Great Lakes District Meeting
Indianapolis-Lafayette Section territory (Date to be determined)

for the encouragement and recognition of "meritorious achievement in the development of electrical apparatus or machinery." By Mr. Lamme's will, 2 other similar bequests were made, one to Ohio State University, and one to the Society for the Promotion of Engineering Education. The Lamme Medal of Ohio State University, to be awarded a graduate of one of the technical departments for meritorious achievement in engineering of the technical arts was presented for 1934 to L. W. Chubb (A'09, F'21, and director) director of research laboratories, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa. The 7th Lamme Medal of the S.P.E.E. was awarded to Prof. E. R. Maurer, professor of mechanics at the University of Wisconsin, during the annual meeting of the society in June 1934.

Medal Presented by D. C. Jackson

At the annual meeting at Hot Springs, Prof. P. M. Lincoln told of Mr. Lamme's interest in the education of engineers and mentioned some of his efforts to further the development of electrical engineering. In this connection, he spoke of the work in which Mr. Lamme and Doctor Stillwell coöperated when the power plant at Niagara Falls was designed in 1893. He pointed out that the adoption for that plant of alternating current, which was sponsored by both Mr. Lamme and Doctor Stillwell, has had a tremendous influence on the subsequent development of the electrical industry.

Prof. D. C. Jackson then outlined the career and the distinguished achievements of the medalist, Dr. L. B. Stillwell. In addition to describing many of the actual accomplishments of Doctor Stillwell, Doctor Jackson spoke of many of the mental qualities possessed by the medalist which made possible his contribution to electrical engineering design, to social welfare, and to education, saying, in part "Imagination coupled with optimism arouses visions which are pictured as capable of actual embodiment, but the pessimism produced by a restraining influence of historical hindsight prevents an over-optimism which might lead to a crash. Curiosity, interest, the intellectual joy of achievement, associate equally with all imaginative productions; and imagination, held definitely to face realities as a plane of origin, is a major tool of engineers. It seemed to me then (Editor's Note: in 1910, while both were officers of the Institute), and I continue of the conviction, that Stillwell held these qualities in high degree, and possessed this tool which he used well. His long-time successful practice as a consulting engineer proves the case."

Doctor Stillwell Responds

In his speech of response, Doctor Stillwell emphasized his deep appreciation of the action of the Institute in conferring the 1933 Lamme Medal upon him, pointing out that to the professional man, commendation of his work by the fellow members of his profession is perhaps his highest reward. He then spoke of "system engineering" referring to the development of electric power systems. It was in this work that his greatest activity was concerned, rather than in the detailed design of electrical machinery. Doctor Stillwell outlined one of the great periods of change in system engineering of a-c work in this country, pointing out that in the 10 years or so following the founding of the Institute in 1884, a tremendous number of new developments in electrical projects were brought about by energetic pioneers.

Doctor Stillwell closed his speech with a plea for the support of the magnificent work which has been carried out by members of the Institute during the last 50 years in the development of high voltage lines covering the entire country, and making available large economies and facilities for providing for emergency conditions. He pointed out that the general public's discontent with economic conditions accentuated by resentment toward some of the organizers of holding companies, has caused our state governments and even the federal government to open the door to the construction of municipal power plants. He pointed out that such a policy weakens the economic stability of the great public utility companies of today, and stated his opinion that the problem should be studied very carefully, but very promptly, and that the whole engineering profession should take a stand for the conclusions reached.

Results—

Total number of applications received for A.I.E.E. membership during:

May 1933—26	May 1934—42
June 1933—26	June 1934—50

The continued coördination of membership activities by the National and Section membership committees through the suggestion of names of those considered worthy to be asked to join the Institute will augment these results.

Everett S. Lee

Chairman National Membership Committee

Celebration of 50th Anniversary

In commemoration of the founding of the Institute in 1884, a "50th anniversary meeting" was held on Monday morning, June 25, during the summer convention at Hot Springs, Va. At this meeting, which followed the Institute's annual business meeting, President Whitehead referred to the 50th anniversary issue of Electrical Engineering (May 1934) and of the various anniversary meetings which have been held throughout the country by the local Sections.

Prof. D. C. Jackson then spoke of the 2 senior living past presidents of the Institute, Dr. Edward Weston and Dr. Elihu Thomson, who were among the very great creators in the electrical industry that are left with us among the older pioneers. From Professor Thomson, with whom Doctor Jackson was recently in contact, a message was conveyed to this 50th anniversary meeting wherein Professor Thomson stated that he was exceedingly regretful that he could not attend as one of the past presidents who were gathered there but that he extended his salutations and wished to express his interest in the Institute and his wishes for its continued success through another jubilee.

Two addresses by prominent members of the Institute featured the anniversary meeting. The first of these, by Dr. W. E. Wickenden, president of Case School of Applied Science, Cleveland, Ohio, was on the subject of "Toward the Making of a Profession." Doctor Wickenden first outlined the many items which comprise the obligations of a profession and the reasons for the growth of professions, and discussed these points with particular reference to the Institute. Essentially full text of the address is given in this issue of Electrical Engineering p. 1143–5.

Doctor McClellan's Address

The other principal address on the 50th anniversary program was that of Dr. William McClellan, past president of the Institute (1921–22). Doctor McClellan, in his address, outlined briefly the principal developments in electrical engineering prior to the founding of the Institute in 1884, and then discussed the development of electrical engineering and some of the personalities involved during the next several years.

Doctor McClellan pointed out that for a "profession" to be successful, it was necessary not only that the members be motivated by ideals of service, but that they must have a unity of action. Using examples taken from the legal and medical profession, he pointed out the advantages of having all engineers, whether civil, mining, mechanical, or electrical, operate through one society, such as, for example, American Engineering Council. He stated his belief that the world will never recognize the engineering profession as on a par with other professions until such unity of thought and purpose is introduced and made apparent to all. In developing this idea, he suggested that graduates of engineering schools should all be given the degree of bachelor of engineering, without designating any particular branch of engineering at that

time. Doctor McClellan closed his address with a plea for the creation of a genuine engineering profession.

At the conclusion of this inspiring meeting, a radiogram conveying heartiest greetings and congratulations on the occasion of the Institute's 50th anniversary, transmitted by the South African Institute of Electrical Engineers, was read.

Other Features

Technical Sessions

All technical sessions at the convention were held during the mornings, and were very well attended. In all, 7 technical sessions had been aranged. At these sessions some 30 papers, most of them on technical subjects, were presented and discussed.

All of the papers presented at the convention appear in the June 1934 issue of Electrical Engineering, except 3 which had been previously published in Electrical Engineering. Discussions of the papers are scheduled for publication in subsequent issues.

Attendance

Although the official registration of 351 was only a little more than a third of the registrations prevailing in 1933 and in 1932, the level was just about equal to the average of previous conventions held in the South. An analysis of the attendance at Hot Springs is given in Table I accompanying, and a comparison of summer convention attendances over a period of 15 years is given in Table II.

Table I—Analysis of Attendance at A.I.E.E. Summer Convention

Classification	Dist. 1	Dist. 2	Dist. 3	Dist. 4	Dist. 5	Dist. 6	Dist. 7	Dist. 8	Dist. 9	Dist. 10	Foreign	Totals
Members	47	79	51	22	26	3	9	5	5	4	1	252
Men Guests	1	8	3	2	1	0	0	0	0	0	0	15
Women Guests	12	31	21	7	10	0	2	0	1	0	0	84
TOTALS	60	118	75	31	37	3	11	5	6	4	1	351

Entertainment

In view of the fact that a rather complete range of facilities was available at the Homestead Hotel, and its subsidiary, The Cascades Inn, practically all entertainment activities centered there. A motor trip to the Greenbrier Hotel at White Sulphur Springs, W. Va., some 47 miles over the mountains from Hot Springs, was the only formally scheduled trip. Quite a large group enjoyed the trip and the refreshments served at the Greenbrier's casino. Monday evening was featured by the president's reception; Tuesday evening by an informal get-together banquet punctuated by impromptu entertainment; and Wednesday evening was the occasion of the annual convention banquet and its generous program of entertainment.

In the women's putting contest, played Tuesday morning by a large number of entrants including several non-golfers, Mrs. John W. Latham, Charlestown, W. Va., won on a play-off with a net score of 37; runner-up was Mrs. R. W. Harris, of New York, whose net score was 40. Other prize winners included Mrs. A. H. Lovell, Ann Arbor, Mich.; Mrs. R. E. Hellmund, Pittsburgh, Pa.; and Mrs. G. L. Weller, Washington, D. C. At the women's bridge-luncheon held Tuesday, the list of

Table II—Summer Convention Attendance During Recent Years

1934	**Hot Springs, Va.**	*** (4)**	**351**
1933	Chicago, Ill.	(5)	968
1932	Cleveland, Ohio	(2)	1,022
1931	Asheville, N. C.	(4)	525
1930	Toronto, Ont., Canada	(10)	1,110
1929	Swampscott, Mass.	(1)	1,000
1928	Denver, Colo.	(6)	500
1927	Detroit, Mich.	(5)	1,200
1926	White Sulphur Spgs., W. Va.	(4)	350
1925	Saratoga Spgs., N. Y.	(1)	900
1924	Chicago, Ill.	(5)	750
1923	Swampscott, Mass.	(1)	1,616
1922	Niagara Falls, N. Y.	(1)	950
1921	Salt Lake City, Utah	(9)	426
1920	White Sulphur Spgs., W. Va.	(4)	314

* District Numbers in parentheses.

prize winners included Mrs. E. B. Meyer, South Orange, N. J.; Mrs. H. A. Holmes, Fairmont, W. Va.; Mrs. L. F. Hickernell, Hastings-on-Hudson, N. Y.; Mrs. W. W. Ballew, Birmingham, Ala.; Mrs. C. L. Dawes, Cambridge, Mass.; Mrs. E. J. Rommel, Toledo, Ohio; Mrs. L. G. Smith, Baltimore, Md.; and Mrs. W. H. Timbie, Cambridge, Mass.

Skeet

Skeet, a new and intriguing form of trapshooting, proved attractive to several who were handy with their shot guns, and others who thought they should be. In the officially recognized tournament, E. P. Coles of Charlotte, N. C., won first honors, with C. O. Bickelhaupt, New York, N. Y., finishing as runner-up, closely followed by L. P. Ferris, New York, N. Y.

Golf

The annual tournament and other officially recognized golfing events were played on the Cascades course, with competition spurred by the many beautiful prizes offered in addition to the Lee and the Mershon trophies. Competition also was intensified by the fact that several were playing with the hope of getting their names on one or the other of the trophies the second time.

The present Mershon trophy is the second cup donated by Past President Mershon, the first having been won permanently in 1931 by L. F. Deming of Philadelphia, Pa., as a result of his having won the right to have his name engraved upon it in 1916 and again in 1931. The trophy had withstood competition since 1912. The new trophy is competed for by match play on a handicap basis, the same as the first trophy and also is subject to permanent possession by virtue of 2 winnings by an Institute member. The 16 men having the lowest net scores in a preliminary qualifying round are privileged to play through 4 successive elimination rounds to determine the ultimate winner. The results of the Hot Springs competition were:

Winner—G. A. Kositzky, Cleveland, Ohio; score 7–5.
Runner-up—H. W. Eales, Chicago, Ill.

Mr. Kositzky, by winning the right to have his name engraved on the Mershon trophy, prevented Mr. Eales from taking permanent possession. The names now appearing on the cup are: L. R. Kieffer, Cleveland, Ohio, 1932; H. W. Eales, 1933; G. A. Kositzky, 1934.

The Lee trophy, presented by Past President Lee in 1932, is competed for annually on the basis of lowest net score for 36 holes; it, too, must be won twice by the same player for permanent possession. The results for the 36-hole medal play at Hot Springs:

Winner—F. M. Craft, Altanta, Ga. (gross score 178, handicap 36, net 142).
Runner-up—T. O. Rudd, New York, N. Y. (gross score 152, handicap 9, net 143).

Names now appearing on the Lee trophy are: C. H. Teskey, Cleveland, Ohio, 1932; G. R. Canning, Cleveland, Ohio, 1933; F. M. Craft, 1934.

Winners of prizes in special events arranged by the local sports committee were:

First low net—E. S. Atkinson, Battle Creek, Mich.; score 67.
Second low net—T. O. Rudd, New York, N. Y., 68.
Blind bogey: winner—G. A. Zehr, Niagara Falls, N. Y.; low gross—T. O. Rudd, New York, N. Y.; low net—W. A. Buchanan, Welch, W. Va.

The "tombstone" tournament aroused considerable interest. The event was opened to members and guests. Each player was assigned the number of strokes represented by the par of the course (71) plus his regularly assigned handicap; the idea being to make the greatest possible distance in the assigned number of strokes, planting his "tombstone insignia" at the point where his ball rested at the end of his final stroke. Prizes were awarded to the several players covering the greatest yardage in the number of strokes assigned as follows:

Winner—W. A. Buchanan, 95 strokes, ball finished on 19th green.
Second place, F. M. Craft, 89 strokes, ball 2.5 ft from 18th hole.
Third, T. O. Rudd, 74 strokes, ball 5 ft from 18th hole.
Low gross, J. H. Irwin, Chicago, Ill., 78.
Low net, James Nichols, Wauwatosa, Wis., score 73.

District team competition, on the basis of 36-hole medal play, was won by a team representing District No. 2 as follows:

C. G. Teskey, C. A. Kositzky, G. R. Canning, and F. Quigley, all of Cleveland, Ohio.

Tennis

With fewer entrants for the tennis tournament than for the golf tournament, the competition was not so widespread. How-

ever, a large gallery very much enjoyed the several lively sets and close scores. The Mershon trophy for tennis was presented by Past President Mershon and has been up for competition since 1927. The trophy is available to Institute members, the winner each year being recognized by having his name engraved on the cup, and receiving a photograph of it, unless it be his second winning, in which event the cup passes permanently into the winner's possession. At Hot Springs, Delegate E. F. Lopez of Mexico City, Mex., won the cup for the second time, and took it back to Mexico with him. Mr. Lopez won from R. B. Stewart of Chevey Chase, Md.; score, 6–3, 6–0, 3–6, 6–2. The winners, as the names were finally engraved upon the cup, were as follows:

1927 G. A. Swain, East Pittsburgh, Pa.
1928 P. H. Hatch, Stamford, Conn.
1929 A. J. Gowan, St. Petersburg, Fla.
1930 E. F. Lopez, Mexico City, Mex.
1931 J. K. Peek, New York, N. Y.
1932 R. A. Monroe, Pittsburgh, Pa.
1933 A. J. Krupy, Chicago, Ill.
1934 E. F. Lopez, Mexico City, Mex.

Committees

Credit for the successful arranging of the number of events comprising the 50th annual summer convention must go to the committees who were responsible for carrying out the work.

The general convention committee consisted of the following members: W. S. Rodman, *chairman;* C. A. Robinson, *vice chairman;* R. C. Bailey, *secretary;* and E. P. Coles, R. N. Conwell, F. M. Craft, S. A. Flemister, J. T. Graff, E. L. Lockwood, W. R. McCann, and I. M. Stein. The chairmen of the various subcommittees working with the general convention committee were as follows:

Hotels and Registration—E. L. Lockwood, *chairman;* H. C. Bailey, R. M. Bush, E. S. Fitz, and J. M. Wilson.
Entertainment—C. A. Robinson, *chairman;* H. A. Holmes, J. W. Latham, A. M. Rosenblatt, J. C. Smith, and C. H. Weber.
Sports—J. T. Graff, *chairman;* Cecil Gray, J. L. Harrington, J. W. Latham, and G. L. Weller.
Technical Sessions—R. N. Conwell, *chairman;* C. S. Rich, *secretary;* F. M. Craft, L. A. Doggett, S. L. Henderson, H. W. Leitch, E. J. Rutan, D. M. Simmons, and D. W. Taylor.
Finance—E. P. Coles, *chairman;* W. E. Mitchell, *vice chairman;* J. S. Miller, Jr., *treasurer;* C. I. Burkholder, N. H. Coit, F. M. Craft, Mark Eldredge, E. S. Fitz, Thomas Fuller, E. H. Ginn, J. W. Hancock, W. S. Lee, Jr., Berrier Moore, J. H. Pagent, and J. E. S. Thorpe.

1934 Lamme Medal Nominations Due Nov. 1

In fulfilment of by-law requirements, a second posting is hereby given to the necessity of all nominations for the Lamme Medal for 1934 being submitted not later than November 1, 1934. (See Electrical Engineering, June 1934, p. 1022–3.) Presentation of the 1933 Lamme Medal was made to Lewis B. Stillwell (A'92, M'92, F'12, member for life and past president), consulting engineer, New York, N. Y., at the opening session of the Institute's recent summer convention at Hot Springs, Va.

A.I.E.E. Directors Meet During Summer Convention

The regular meeting of the board of directors of the American Institute of Electrical Engineers was held at The Homestead, Hot Springs, Va., June 27, 1934, during the annual summer convention of the Institute.

Present: *President*—John B. Whitehead, Baltimore, Md. *Past President*—H. P. Charlesworth, New York, N. Y. *Vice Presidents*—R. B. Bonney, Denver, Colo.; F. M. Craft, Atlanta, Ga.; J. Allen Johnson, Buffalo, N. Y.; E. B. Meyer, Newark, N. J.; and R. W. Sorensen, Pasadena, Calif. *Directors*—L. W. Chubb, East Pittsburgh, Pa.; B. D. Hull, Dallas, Tex.; P. B. Juhnke, Chicago, Ill.; A. E. Knowlton, New York, N. Y.; G. A. Kositzky, Cleveland, Ohio; A. H. Lovell, Ann Arbor, Mich.; L. W. W. Morrow, New York, N. Y.; A. C. Stevens, Schenectady, N. Y.; R. H. Tapscott, New York, N. Y.; and H. R. Woodrow, Brooklyn, N. Y. *National treasurer*—W. I. Slichter, New York, N. Y. *National secretary*—H. H. Henline, New York, N. Y. By invitation: *Past Presidents*—Bion J. Arnold, Chicago, Ill.; A. W. Berresford, New York, N. Y.; Dugald C. Jackson, Cambridge, Mass.; Paul M. Lincoln, Ithaca, N. Y.; William McClellan, Washington, D. C.; Charles F. Scott, New Haven, Conn.; Lewis B. Stillwell, Princeton, N. J.; also *officers-elect*—F. M. Farmer, New York, N. Y.; N. E. Funk, Philadelphia, Pa.; H. B. Gear, Chicago, Ill.; F. J. Meyer, Oklahoma City, Okla.; and W. H. Timbie, Cambridge, Mass; and C. O. Bickelhaupt, New York, N. Y., an Institute representative on Coördination Committee of Engineering Societies.

Minutes of the meeting of the board of directors held May 25, 1934, were approved.

A report of a meeting of the board of examiners held June 20, 1934, was presented and approved. Upon the recommendation of the board of examiners, the following actions were taken: 2 applicants were elected and 8 were transferred to the grade of Fellow; 4 applicants were elected and 32 were transferred to the grade of Member; 102 applicants were elected to the grade of Associate; 121 Students were enrolled.

The finance committee reported disbursements for the month of June amounting to $17,939.27. Report approved.

Report was made of appointments, upon nomination of the standards committee, of representatives on committees of the American Standards Association, as follows: Edward E. Ashley, representative, M. Freund, alternate, on sectional committee on ventilation code; J. B. Russell, a representative on sectional committee on standardization of vacuum tubes for industrial purposes; W. H. Lesser, representative on the mining standardization correlating committee.

Recommendations to the board of directors adopted at the Conference of Officers, Delegates, and Members, held on June 25 and 26, at Hot Springs, Va., were presented and referred to appropriate committees for recommendation.

President-elect J. Allen Johnson was appointed a representative of the Institute on the Assembly of American Engineering Council, effective August 1, 1934, succeeding the retiring president, Dr. J. B. Whitehead.

The board adopted resolutions of appreciation of the effective services of the 1934 summer convention committee and subcommittees and of the ladies' entertainment committee in arranging for the comfort and entertainment of the members and guests in attendance at the annual summer convention, Hot Springs, Va., June 25–29, 1934.

Other matters were considered, reference to which may be found in this or future issues of Electrical Engineering.

Last Call for the Pacific Coast Convention

All is in readiness for the Pacific Coast convention, which will be held in Salt Lake City, Utah, September 3–7, 1934, with headquarters in the Hotel Utah. The general convention committee, under the chairmanship of B. C. J. Wheatlake, has arranged an excellent series of events—5 technical sessions, 2 Student sessions, with sports and ample opportunity for recreation in this scenic vacation land. With Yellowstone National Park but a night's ride from Salt Lake City, and such scenic wonders as the Grand Canyon, Zion and Bryce Canyons within the boundaries of Utah and Northern Arizona, members are offered unusual possibilities to combine a few vacation days with the convention trip. There is also a possibility of combining a trip to Boulder Dam, now at its most interesting construction stage, with the convention trip to the Utah Parks.

Technical Program

A technical program of 5 sessions—communication, management and protective devices, lightning, transmission, and selected subjects—has been scheduled with one session a day during the interval of the convention. In addition Student sessions will be held on the afternoons of Tuesday and Wednesday, September 4 and 5, respectively. The program is of broad scope, containing a number of papers by well-known western engineers, which deal with recent developments in their localities, and these have been combined with papers from the east on new developments and operating practice, which should be of particular interest to western engineers. For a more complete account of the convention and the technical program see the July issue of Electrical Engineering, p. 1128–29 and 1127. For the papers which have been previously published reference to the issue

Table I—Hotel Rates

	Rooms With Bath	
Hotels	Single	Double
Hotel Utah	$2.50	$3.00–4.00
Hotel Newhouse	$2.50, 3.00, 3.50	$3.00, 3.50, 4.00
Hotel Temple Square	$2.00	$2.50

and page is given after each title on the program. The remaining papers on the program which are not so indicated are published in this issue.

Hotel Rates and Accommodations

Very reasonable rates at the headquarters hotel, the Hotel Utah, and several other recommended hotels are shown in Table I. Members should make their reservations directly by writing to the hotel of their preference.

Keep abreast of your profession and enjoy a few vacation days in this region of scenic splendor by attending the Pacific Coast convention at Salt Lake City, September 3–7.

Officers, Delegates, and Members Hold Annual Conference at Hot Springs, Va.

HELD jointly under the auspices of the Sections committee and the committee on Student Branches, the regular conference of officers, delegates, and members of the Institute, was held at Hot Springs, Va., Monday and Tuesday afternoons, June 25–26, 1934, as a part of the summer convention activities. Present at these sessions were delegates from 55 Institute sections, and counselor-delegates from 6 of the 9 districts in which committees on student activities have been organized. In addition to these formally constituted delegates, there were other officers, officers-elect, and Institute members, bringing the recorded attendance total up to 101. The principal topics under discussion at the conference were as outlined in a program previously mailed to the delegates and others:

Monday, June 25, 2:00 p.m.

1. Opening of conference; Announcements by I. Melville Stein, chairman of the sections committee.
2. Remarks by President J. B. Whitehead.
3. Remarks by President-Elect J. Allen Johnson.
4. Remarks by National Secretary H. H. Henline.
   a. Report on action on recommendations made last year.
   b. General Institute affairs.
5. Institute finances—E. B. Meyer, chairman, finance committee.
6. Division into parallel sessions.

Session A—Sections Committee Meeting—I. Melville Stein, Chairman, presiding

7. Communication from membership committee—Everett S. Lee, chairman, membership committee.
8. Section and District technical committee activities—Prof. N. S. Hibshman, Chairman Lehigh Valley Section.
9. Institute dues—J. Allen Johnson, chairman, special committee to consider dues of associates and related matters.
10. The Electrical Engineer and the Codes—J. B. Whitehead, president.
11. General discussion on improving Institute activities.

Session B—Student Branch Committee Meeting—Prof. L. A. Doggett, Chairman, presiding

12. Reading of Annual Report.
13. Student and associate member statistics.
14. Qualifications for student membership.
    Shall students, taking certificate courses, extension courses, or other work not equivalent to the work of a technical school of recognized standing, be admitted to the privilege of student membership? Cases of (*a*) University of Cincinnati, (*b*) Franklin Union, (*c*) University of Minnesota.

Tuesday, June 26, 2:00 p.m.

Session C—General

15. Report on Student Branch committee meeting—Prof. L. A. Doggett, chairman, student branch committee.
16. Résumé of Monday's sections committee meeting discussion—I. Melville Stein, chairman, sections committee.
17. "Engineering: A Career—A Culture"—Prof. L. A. Doggett. (A communication from the Engineers' Council for Professional Development.)
18. Continuation of discussion on improving Institute activities.
19. The coming year—President-Elect J. Allen Johnson.

Inasmuch as the Annual Report on Sections and Branch Activities was published in full in the June 1934 issue of Electrical Engineering (p. 1037–9), no pamphlet copies of the report were prepared for use at the meeting, and nothing further remains to be reported here.

Opening Session

President Whitehead in his brief introductory remarks expressed pleasure at being able to attend the conference, stating that in his opinion a conference provided an excellent opportunity for better mutual acquaintance and understanding among the leaders in Institute activities and "as a most important and interesting occasion for those who are entrusted with the administrative and executive functions of the Institute to learn what the members are thinking about."

J. Allen Johnson, responding briefly to his introduction as president-elect of the Institute, mentioned the fact that inasmuch as $^2/_3$ of the Institute membership resided in Section territory, "certainly the desires and influence of the Sections must bulk large in Institute policy. At the same time we must always keep in mind the minority who do not have the opportunity to take part in Section activities." He urged active and thoughtful coöperation in the promotion of Institute affairs, and indicated that in the administration of his office as president his own large store of experience in Institute activities (Branch chairman, Section chairman, chairman of membership and other important committees, District vice president) would be drawn upon liberally.

National Secretary and Finance Chairman Report

National Secretary Henline reported in some detail the present status of the various recommendations made at the 1933 conference in Chicago. (See Electrical Engineering: August 1933, p. 576–7; Sept. 1933, p. 640; Nov. 1933, p. 794; and other issues.) Concerning general Institute activities, Secretary Henline had the following comments to offer:

"As has been mentioned several times, one of the most important items in Institute work and one to which we must always be giving consideration, is the need for bringing into the activities more of the members who are qualified to carry them on effectively, and a good many things have been done in recent years in that direction. . . . I think this (conference) is the greatest opportunity we have for improving Institute affairs. . . . Of course, we haven't solved all our problems and we never shall. . . . Certainly as we expand Institute activity to bring in more individuals, there will be more subjects requiring discussion and consideration instead of fewer. These activities offer wonderful opportunities alike for the student, the young graduate, and the more experienced engineer; thus the Institute is doing everything possible within its means to provide something of interest and attractiveness for all members from the youngest to the oldest.

"One of the principal purposes of such conference as this is to seek out these new ways in which the Institute may make itself helpful to its members and to its prospective members . . . a large number of the Institute policies and procedures have resulted directly from these conferences. . . . . This annual meeting . . . a few years ago was called a Section delegate conference and Sections committee conference . . . (but has been) broadened so that now it is called a conference of officers, delegates, and members, so that anyone in these various groups is at liberty to come to listen and take part in the discussion. As these conferences have served effectively in the past, so do they hold still greater possibilities for the future."

E. B. Meyer, finance committee chairman, presented facts and figures representing a résumé of his illuminating article "The Story of the Institute Budget" that was published in the March 1934 issue of Electrical Engineering. Supplementing this, Mr. Meyer reported that for the first 9 months of the current appropriation year, October 1 to June 30, the Institute's income had slightly exceeded the expenditures for the same period, an improvement over last year's condition, which in turn was an improvement over that of the preceding year. Mr. Meyer reported also that the outlook for the remainder of the appropriation year was such that an originally contemplated withdrawal from the Institute's reserve fund probably would not be required; further, that the market value of the securities held by the reserve fund had appreciated in market value.

Sections Session

Before launching into the business program of the session, Chairman I. M. Stein

recognized and expressed appreciation for the work done by the program committee: F. L. Christenbury of the Memphis Section, Raymond Foulkrod of the Detroit Section, and R. L. Kirk (chairman) of the Pittsburgh section.

Membership Committee Reports

A report on the activities of the Institute's membership committee prepared by E. S. Lee, chairman of that committee, was read by E. P. Coles in Mr. Lee's absence. The report, essentially in full, follows:

"When we speak of the work and activities of the membership committee of the Institute, we are really speaking of the work and activities of some 600 members coordinated with the 15,000 members of the Institute. Such an organization and such a conception is bound to succeed and we feel that we are succeeding. We have an admirable Institute to which to invite those who, we feel, should become members with us.

"During the year we have appealed on 2 occasions to the entire membership to send in the name of a person considered worthy to be asked to join the Institute. While we have made an effort to ascertain how many names were so sent in, it has been somewhat difficult to obtain totally reliable figures, but from data presented it seems that one application is obtained for about 7 names submitted. Assuming that $^1/_2$ of the 500 applications from other than students received last year resulted from such contribution of names, it would mean that about 1,500 members aided in this work. I do not think this number is large enough and therefore feel that the membership committee is right in continuing its present policy of trying to interest the present membership in seeking out worthy persons to become associated with us.

"From the larger membership the activities of the membership committee center in the Section membership committees who through the chairman deal with a District vice chairman who with 4 members-at-large provide a smaller group with whom the chairman can consult. I must admit this year that being new to the work I suggested a policy at the beginning of the year which was generally approved by the vice chairmen and this I have tried to carry out without further consultation but I am sure that anyone has felt free at any time to send in suggestions and several suggestions have been received which we have tried to act upon with advantage.

"Each month a report of membership statistics has been sent to the chairman of each Section membership committee together with copies to the chairmen and secretaries of each Section, copies to the District vice chairmen, and copies to the members of the board of directors. This has given opportunity to keep everybody informed of the progress of the work and I believe that if the Section activities can be coördinated around these reports, we have a strong and forceful means whereby the activities of the membership as a whole may be carried on efficiently and to the satisfaction of all."

Major Objectives

"The membership committee sought the following 3 major objectives:

1. To contact for new members.
2. To contact Students eligible to become Associate members.
3. To contact member for reinstatements.

"In regard to the first objective, the final report of the membership committee for the year shows that applications for membership were received from every Section of the Institute and this, I believe, is cause for gratification on your part. With the continuance of your interest in membership activities this record should be maintained and the total number increased month by month. It seems to me that this might well be our bogey that the number of applications received each month should be more than received in the same month of the preceding year. For the first month of this year, May 1934, we have made that bogey in that total applications received for May 1934, were 42 while during May 1933, they were 26. With your help this bogey will be made.

"In regard to the second objective, while it is the responsibility of the committee on Student Branches to provide for our Students, it is the responsibility of the membership committee to see that Students are brought into Associate membership as they become eligible. The number of Students brought into Associate membership this year was not as large as last year. Undoubtedly there are reasons for this but I feel that the Section membership committees should give increasing time, thought, and attention to this phase of our activity and with the help of the Section officers I am sure that we can bring about the same attainment as regards bogey results as with those who are not Students. So far this year we have not made this bogey for in May 1934, no applications were received from Students for Associate membership while in May 1933, 7 such applications were received. It is interesting to note, however, that during the past year applications from Students to enter Associate membership were received from every Section of the Institute except 3.

"Our third objective to contact members for reinstatement has been a part of our work which has been particularly happy for those who have participated in it and the record shows that since August 1, 1933, there have been 637 reinstatements. As chairman of the membership committee and as a member of the board of directors I feel that our board of directors not only this year but in the past years has been very thoughtful in dealing with those who have not been able to pay their dues regularly and I believe that if you could know intimately of all the cases that have had to be handled, you would be inspired, enthused, and

One of the Scenic Features Near Salt Lake City

ALTHOUGH the majority of those members of the Institute who will attend the 1934 Pacific Coast convention at Salt Lake City, Utah, Sept. 3–7, will be attracted primarily by the technical papers outlining recent advances in a number of fields of electrical engineering, the many scenic features offered by that section of the country provide an additional incentive for attendance at the convention. Many members are making plans to attend with their families, and will combine the opportunities of acquiring technical information with the pleasure of a vacation trip. The view shown here was taken from the Alpine Highway in north central Utah, and shows Mount Timpanogas in the background. Mount Timpanogas, highest of the Wasatch Mountains, rises to 11,957 feet above sea level.

pleased both with the resolutions emanating from the board of directors in these respects and from the thoroughness with which our headquarters' staff has handled the enormous correspondence in this regard. Since August 1, 1933, there have been reinstatements in every Section of the Institute except 3, which again speaks for the universality of this work."

The report mentioned the fact that no statistics are included, but that complete statistics covering the entire phase of the work included were given in the report of the board of directors for the fiscal year ending April 30, 1934, published in ELECTRICAL ENGINEERING for July 1934, p. 1095–107. The report concluded with an appeal for sustained endeavor by the chairmen of the various Section membership committees. It also requested of the entire membership "your individual and official interest in this work that there may be brought into our Institute for association with ourselves all of those who are interested in our aims and ideals and who should rightfully be associated with us."

SECTION TECHNICAL COMMITTEES PROPOSED

The proposal (see p. 631, April 1934 issue ELECTRICAL ENGINEERING) to broaden the opportunity for individual participation in Section activities, and for Section participation in national activities, through the establishment of provision for Section and District technical committees, was extensively discussed at both afternoon sessions of the conference. Several points of apparent confusion were cleared up in the discussion. It was clearly established that the basic idea of the proposal was principally to establish a definitely recognized basis for uniformity so far as possible Section technical activities were concerned, and to establish definite relationship between such activities and the Institute national organization in so far as its 18 technical committees are concerned. Also, it was emphasized that the whole idea is permissive rather than mandatory. At the close of discussion on the subject, the following resolution was adopted:

RESOLVED: That this conference recommends to the board of directors of the American Institute of Electrical Engineers that such changes be made in the by-laws of the Institute as will provide for an expansion in function and membership of the national technical committees and for the creation of District and Section technical committee activities. It is suggested that these results may be accomplished in the following manner:

1. Let each Section be authorized at its own discretion, and on its own initiative, to organize within its membership, technical committees corresponding in name and scope to any or all of the recognized Institute technical committees.
2. Membership in a Section technical committee shall be open to any Fellow, Member, and/or Associate of the Institute who is a member of that Section and who shall signify his wish to participate in the activities of that Section technical committee.
3. Each Section technical committee shall consist of a suitable number of Fellows, Members, or Associates of the Institute; shall have a chairman selected in a manner determined by the Section; and this Section technical committee chairman shall be a member of the District technical committee.
4. The vice president of each District shall appoint, with the advice of the committee, annually one member of each District technical committee to serve as a member of that national technical committee and to be chairman of his District technical committee.
5. The president of the Institute will appoint annually members-at-large to each national technical committee, and will designate its chairman as is the present practice.

This resolution was considered by the board of directors at its Hot Springs meeting, June 27, at which time the board voted to refer the recommendations to the technical program committee, the chairmen of the technical committees, and the Institute policy committee for study, and report to the board of directors at its next meeting, scheduled for August 14, 1934.

JOHNSON DISCUSSES INSTITUTE DUES

The question of Institute dues was discussed by President-Elect J. Allen Johnson,

Presidential Group at the 1934 Summer Convention, Hot Springs, Va., June 25–29

The largest group of Institute presidents assembled during recent years was present at Hot Springs for the celebration of the Institute's 50th anniversary. From left to right: J. Allen Johnson, 1934–35; D. C. Jackson, 1910–11; H. P. Charlesworth, 1932–33; Louis B. Stillwell, 1909–10; Comfort A. Adams, 1918–19; Bion J. Arnold, 1903–04; Charles F. Scott, 1902–03; A. W. Berresford, 1920–21; William McClellan, 1921–22; P. M. Lincoln, 1914–15; and J. B. Whitehead, 1933–34

chairman of the special committee on Associate dues, who stated that the only bases on which dues are likely to be criticized are that the average dues are too high, that they are not properly distributed over the different grades of membership, or that the right uses are not made of the dues after they are collected.

Mr. Johnson cited evidence for concluding that the average dues are not too high, and that there appears to be no good reason to question the uses to which dues are put after collection. In regard to the second basis, namely, the distribution of dues over the different grades of membership, he pointed out the logical reasons for the present arrangement, and also some of the difficulties, largely psychological in origin, which have resulted from it. He indicated that some of the other societies had avoided these difficulties by establishing separate grades of membership for certain classifications now included by the Institute in the one grade of Associate. This suggested the desirability of establishing in the Institute a "Junior" grade to meet the needs of the younger members and to take the place of the present anomalous 6-year period of $10 Associate membership. At the session held the following day a resolution was adopted endorsing this suggestion.

Student Branches Session

As a result of an afternoon's deliberation on the part of student counselors and other interested persons in attendance at the session, the student Branches group adopted unanimously the following resolution:

Resolved, that the student Branches committee requests that:

(a) An assistant editor in charge of student matters be appointed. His duties shall be to prepare 2 pages per issue for Electrical Engineering under the supervision of Mr. Henline and Mr. Henninger. These pages shall be made attractive to our student members incorporating such items as Branch news, editorial comments of current technical and other material similar to students' page in the "London Electrician."

(b) He shall as rapidly as possible qualify to take on the duties formerly performed by Mr. Henline when he was assistant national secretary.

In brief, we recommend that steps be taken to initiate the reëstablishment of the office of assistant national secretary with student activities as its chief responsibility.

Closing General Session

In presenting the foregoing resolution before the reconvened joint session, L. A. Doggett, chairman of the student Branches committee, spoke of the high proportion of new members that now are coming from the ranks of former Enrolled Students, and emphasized the necessity of continuing to promote student participation in A.I.E.E. affairs. He characterized as "a very serious loss" the discontinuance of the services of an assistant national secretary.

The proffered resolution was endorsed unanimously by the joint session and forwarded at once to the board of directors for consideration. When the resolution came before the board June 27 it was the consensus of opinion of that body that the resolution could not be acted upon by them as worded; therefore the resolution was referred to the chairman of the finance committee and the national secretary for advice and recommendation.

E.C.P.D. Request

Chairman Stein, speaking as chairman of the A.I.E.E. Sections committee concerning a request for coöperation received R. L. Sackett, dean of engineering at Pennsylvania State College and chairman of the committee on student selection and guidance of the Engineers' Council for Professional Development, requested L. A. Doggett, chairman of the A.I.E.E. committee on education and student Branches, to read the following letter from Dean Sackett:

"The following statement will, I hope, give you an idea of what the committee proposed and also serve as a text for discussion of the subject at the A.I.E.E. meeting.

"The instructions by the E.C.P.D. to the committee on selection and guidance stated that it was:

" 'To develop further means for the educational and vocational orientation of young men with respect to the responsibilities and opportunities of engineers. . . . '

"First, the committee carefully considered all the guidance literature available and after due deliberation a subcommittee consisting of Dean O. J. Ferguson and Prof. W. B. Plank reported that 'Engineering: A Career—A Culture' was the most suitable for the present purpose of the committee.

"Second, the committee considered methods by which guidance agencies could be provided in the more important centers.

"It was also deemed important that some measure of the effectiveness of the pamphlet 'Engineering: A Career—A Culture' should be provided and tried out. This was done by preparing 2 sets of questions for use by a small group of engineering colleges who were asked to invite local high school juniors and seniors to a meeting. A set of questions was given each student at the beginning of the program to test his knowledge of engineering. He was then given a series of short talks and a copy of the pamphlet to read carefully. He then answered a second set of questions. One conclusion was clear. It is expressed by the comment, 'I did not know the field of engineering was so broad'; therefore the pamphlet is helpful.

"A second set of objective tests is now being revised by a specialist in New York with the aid of funds provided for this purpose by The Engineering Foundation. When this set of questions is completed it will be tried out in a few engineering institutions in order to test the validity of the tests; second, in order to bring the institution in contact with prominent local counselors of engineering education; and third, to test the value of the pamphlet, 'Engineering: A Career—A Culture' as a guide to high school students. The procedure should also serve as a guide in selecting the best students or those who would profit most from pursuing an engineering curriculum. One set of questions is to be given to the interested students before they have read the pamphlet and the second set afterward.

"If the foregoing procedure gives promising results, an appeal then will be made to local Sections of the coöperating societies to set up a guidance committee, council, or bureau to make contact with the high schools in that territory and to pursue such guidance methods as may be considered most effective considering all of the local circumstances. The pamphlet on 'Engineering: A Career—A Culture' should be an important informative agency which may be supplemented by talks to interested groups or by individual conferences of prospective students with local counselors. The best technique to pursue will depend on the tact and interest of local Section officers in presenting the subject to high school principals and superintendents and in getting interested high school students together for the purpose.

"Since certain preliminary tests have been given which showed the desirability of guidance and the need for reliable information such as is contained in the pamphlet on 'Engineering' the preliminary period necessary to test out the new objective tests should be short, and Sections may expect a general appeal in October or November for assistance in carrying out the above suggested program.

"Further information will be given you concerning the method of handling the tests and sending the results in to me for tabulation and report to the E.C.P.D."

The consensus of the opinions of delegates present, arrived at through subsequent discussion, was that when Dean Sackett and the E.C.P.D. committee had carried its work far enough to make specific suggestions to or requests of local Sections, the Sections would "agree to coöperate within the bounds of their ability."

Institute Activities Discussed

A brief résumé of some of the principal topics presented during the "Discussion on Improving Institute Activities" is given in the following paragraphs.

J. M. Todd, delegate from the New Orleans Section (the Institute's newest), cited the rapid growth of interest in New Orleans and spoke with great emphasis concerning the necessity for greater local Section activity. R. L. Kirk of Pittsburgh, Pa., urged a general improvement in Institute activities, a strengthening of barriers that would prevent non-members from profiting so generally by Institute activities, and a strengthening of requirements for Institute membership. E. J. Rommel, Toledo, Ohio, Section delegate, reported that Section's success in having members make short informal talks preceding the regular programs at Section meetings, and in conducting forum groups meeting every 2 weeks "to discuss matters other than technical, to take in economic, world wide problems, and things of that kind." He also urged that Sections report successful activities so that they could be reflected and an exchange of ideas effected through Electrical Engineering.

P. L. Alger of Schenectady, N. Y., pointed to the recent outstanding success of the annual convention of the Society for the Promotion of Engineering Education held at Cornell University, Ithaca, N. Y., the week before the A.I.E.E. Hot Springs convention, emphasizing the fact that some 65 technical sessions and conferences were held, and urging that future A.I.E.E. conventions should have many more sessions with fewer papers per session and more opportunity for group discussion by those really interested in the various topics.

President-Elect J. Allen Johnson, in speaking on his assigned topic "The Coming Year," stated that he hoped that the "Institute in the coming year and in all coming years will not lack the courage to make experiments and changes to keep abreast of the changing conditions." He urged Section delegates to find ways and means of better acquainting members of the various Sections with the national activities of the Institute, "referring particularly to the joint activities of the national society which are being carried on for the benefit of the whole profession of engineering," such as the Engineers' Council for Professional Development, and the American Engineering Council. He called attention also to the fact that next year's summer convention is slated to be held at Cornell University, Ithaca, N. Y., urging full coöperation throughout the year in order that all possible opportunities might be developed for the enlargement of summer convention activities.

Doctor Whitehead Explains Proposed Code for Engineering Division of Construction Industry

SPEAKING on the assigned topic "The Electrical Engineer and the Codes" at the Sections session of the annual conference of officers, delegates, and members, held Monday afternoon, June 25, 1934, at Hot Springs, Va., Dr. J. B. Whitehead, retiring president of the A.I.E.E., presented the results of his investigation into the question of the code for the construction industry and its effect on electrical engineers. The full text of Doctor Whitehead's address on this subject follows:

The NRA and the Position of the A.I.E.E.

In the spring of 1933, along with all other organizations, the Institute was asked through the mail to subscribe to the principles of the NRA and to follow this up with the submitting of a code for the regulation of its activities. The Institute subscribed to the principles aimed at in the NRA, but on information from American Engineering Council that counsel of the NRA had advised that the proposed regulations were not intended to apply to scientific and professional societies, and on similar advice from its own counsel, the board of directors determined that no further action in the matter was indicated for the Institute.

During succeeding months several inquiries and resolutions were received at Institute Headquarters from Sections of the Institute asking for information as to a proposed code for engineers, and urging the Institute to combat the adoption of a code that was being proposed by the construction industry, and which included a chapter or division for engineers engaged in that industry. The grounds for the proposed action were that the code being prepared for these engineers was so general in its terms as to make it appear possible at least that electrical and other engineers might be considered as subject to its provisions.

As a consequence of these communications, the board of directors has considered this matter at several of its meetings. It has taken no action, principally because no evidence was presented that any considerable number of electrical engineers could possibly be considered as subject to the code, and because there was no proposal nor suggestion of other grounds upon which possible action might be based. As time has advanced it also has been evident that those who were interested in the formulation of a suitable code for the engineering division of the construction industry, were giving it the most careful consideration with a view to limiting its application, and were well informed as to contemporary discussion and criticism. As a consequence several successive drafts have been prepared, and in its final form now under consideration by the NRA the code appears to contain no features which need give members of the Institute any concern.

A copy of the final draft of the code is printed in *Civil Engineering* for June 1934, together with an interpretation (by Carlton S. Proctor, chairman of the Code Committee of the American Society of Civil Engineers) of how it will operate. I have read these documents with some care and with special thought for the interests of electrical engineers, and I invite your attention to the following:

Code Limited to Construction Industry

In the first place, the code is for the construction industry and is limited to services "for the construction or anticipated construction of any private or public buildings, structures or works, or construction accessory thereto, where such services involve a knowledge of engineering laws, formulas, and practice, and a knowledge of the physical properties of the materials of construction and methods of installation."

All codes are written to insure fair practice among employers, and so are strictly employers' codes. The description in the foregoing paragraph indicates clearly that this code is meant to apply to employers engaged in "construction of buildings, structures or works, and construction accessory thereto."

However the construction industry is defined as including the designing as well as the construction of buildings and fixed structures. For this reason, the code itself contains a division described as the Engineering Division of the Construction Industry. Accordingly, the application of the code is extended to those who are engaged *competitively* in the business of proffering or rendering architectural or engineering service in the form of design for new or anticipated new construction.

This at once eliminates from the application of this code the Federal Government, states, cities, and all other political subdivisions, railroads, utilities, constructors, manufacturers, institutions, and all others, until they shall engage in *competition* on the basis of design for projected construction. The term "engineering service" includes the offer to provide or the providing of engineering service such as investigation, studies, surveying, planning, designing, supervision, inspection, testing or laboratory analyses for *construction only* as defined in the foregoing. It does not include engineering services necessarily adjunctive to the manufacture, sale, installation, or construction of patented devices or specialized processes or engineering design adjunctive to particular processes or particular equipment or combinations of the same. As an example, I suggest that in the erection of a hydroelectric power plant, the application of the engineering division of the construction industry would be limited to the contractors on the buildings, dams, foundations of turbines, generators, etc., but not beyond these foundations, and only when on a competitive basis.

Does Not Affect Electrical Engineers

Furthermore, it is clearly stated that in the case of an architect, landscape architect, consulting or other type of engineer who might be qualified and called upon to furnish engineering services for construction features, such engineers are subject to this code only when in competition and only to the extent as related to such construction, and are free of its conditions in their other activities.

It is difficult to see where in the provisions of this code the interests of electrical engineers are seriously affected. I have been able to think of only one case in which it might apply directly to electrical engineers, namely, in the electric welding of welded steel buildings and structures. It is conceivable that a company engaged in such work might wish to retain the services of electrical engineers expert in this field and these, accordingly, would become subject to the provisions of the code. Obviously, engineering employees of such a firm would also be so subject, but in this latter case, it is difficult to see how their position would be any different from that of engineers employed in any other types of industry, all of which are themselves subject to codes solely when in competition and for the insuring of fair practices among *employers*. In these cases no code for engineers is involved, but only a code for employers.

It is possible that other cases might be cited, but I think it impossible that any considerable number of our members will be found to be subject to the conditions of this code. Incidentally, there is no reference in the code to electrical engineers, nor do the words "electric" or "electrical" appear in it anywhere.

Prominent Consulting Engineer Dies

Carl Ewald Grunsky, consulting engineer of San Francisco, Calif., and past president of the American Society of Civil Engineers and of the American Engineering Council, died June 9, 1934. He was a native of California, having been born near Stockton in 1855. He received his technical education at Stuttgart, Germany, after which he entered public works in California. He was city engineer of San Francisco 1900–04 and on the Panama Canal Commission in 1904. He has been engaged as a consultant on many important works.

Mr. Grunsky received the Norman medal of the American Society of Civil Engineers in 1910, and was president of that society in 1924. He served as president of the American Engineering Council in 1930, and was president of the California Academy of Sciences. Several books on engineering subjects were written by him. His sons, C. E. Grunsky, Jr., and E. L. Grunsky, are consulting engineers in Oakland and San Francisco, Calif.

Additional Awards for 1933 Institute Papers

In addition to the national and District prizes for papers presented before the Institute during the calendar year 1933, as

announced in ELECTRICAL ENGINEERING for June 1934, p. 1026, announcement now has been made of the award of prizes for Districts No. 6 and No. 8. These awards are:

DISTRICT No. 6

Prize for branch paper awarded to Albert E. Logan and Stewart W. Hannah for their paper "The Measurement and Control of the Synchronous Machine Torque Angle," presented at a joint meeting of the Denver Section and University of Colorado Branch, April 28, 1933.

DISTRICT No. 8

Prize for initial paper awarded to A. H. Albrecht (A'14, M'29) for his paper "Variable Voltage Oil-Well Drilling Equipment," presented at the winter convention, New York, N. Y., January 23–27, 1933.

Prize for branch paper awarded to John H. Genzenhuber for his paper "An Experimental Study of Series Modulation," presented at joint meeting held at California Institute of Technology, April 4, 1933.

Date for International Commission on Illumination Selected. The next session of the International Commission on Illumination, as announced in ELECTRICAL ENGINEERING for October 1933, p. 722, and February 1934, p. 360, is to be held in Berlin, Germany, in 1935. Information has recently been received through the central office of the commission in London that the German National Committee affiliated with the commission has chosen the latter half of June, and probably the last week, as the time for the session. Although there will be no general illumination congress like those held in America in 1928 and in Great Britain in 1931, the meetings will afford a comprehensive review of the developments in illuminants and illumination practice taking place in Europe. Information may be obtained from G. H. Stickney, secretary-treasurer of the U.S. National Committee, I. C. I., Nela Park, Cleveland, Ohio.

Letters to the Editor

CONTRIBUTIONS to these columns are invited from Institute members and subscribers. They should be concise and may deal with technical papers, articles published in previous issues, or other subjects of some general interest and professional importance. ELECTRICAL ENGINEERING will endeavor to publish as many letters as possible, but of necessity reserves the right to publish them in whole or in part, or to reject them entirely.

STATEMENTS in these letters are expressly understood to be made by the writers; publication here in no wise constitutes endorsement or recognition by the American Institute of Electrical Engineers.

Theory of Probability

To the Editor:

The most interesting article by Professor Bennett on "Theory of Probability" published in the November 1933 issue of ELECTRICAL ENGINEERING, p. 752–7, called forth a "Letter to the Editor" by Mr. S. A. Smith, Jr., published in the January issue of ELECTRICAL ENGINEERING, p. 229–30. In this letter Mr. Smith raised a very important question about application of theory of probability to the problem of determining the proper number of spare units in the electric system.

In this connection I should like to call your and Mr. Smith's attention to the fact that I had made an attempt to solve for some time the above mentioned problem in some more definite way also by application of theory of probability and had published an article on the subject in the No. 20, 1932 issue of *Electricity* (U.S.S.R.) under the title "The Method of Economic Valuation of the Spare Capacity of Electrical System."

Very truly yours,
R. A. FERMAN
(Electrical Engineer,
Moscow, U.S.S.R.)

Electrical Characteristics of Impregnated Cable Papers

To the Editor:

I have just received the following letter (which I have translated from the German) concerning the paper "Electrical Characteristics of Impregnated Cable Papers" by Professor Humphries and myself. It occurred to me that the suggestions contained therein might interest others who are working on dielectrics. The letter follows:

Diplomingeniör A. Basberg
Torp Brugs A/S
Fredrikstad
Norwegen

An den Associate Professor of Electrical Engineering
C. L. Dawes
The Harvard Engineering School
Cambridge, Mass.
America

Permit me to refer to the paper "The Electrical Characteristics of Impregnated Cable Papers," in the A.I.E.E. TRANS., v. 52, 1933, p. 711–20. In this connection, I should like to have your attention called to a paper which I presented in the fall of 1932 at a meeting of the Norway paper engineers and manufacturers in Oslo, and which was published in the professional journal *Papier-Journalen*, Nos. 11 to 14, 1933, under the title "Die Einwirkung der Feuchtigkeit und Temperatur auf Festigkeits- und Elastizitätsverhaltnisse im Papier." (The Influence of Moisture and Temperature on Strength and Elasticity Relations in Paper.)

Based upon an extensive amount of research material in this work, laws for the strength and elasticity variations of unimpregnated cable papers for various moisture contents and temperatures have been drawn up. From the curves one readily deduces that an unimpregnated cable paper under variable temperature shows a strength curve which has a maximum at about 50 deg C.

It now seems probable to assume that in the judgment of the variations of the electrical characteristics for impregnated cable paper these can be traced back to the above-mentioned relationships for unimpregnated paper.

From the results of the aforesaid researches with unimpregnated cable paper, a theory for the cause of the strength characteristics has been deduced in which the opinion is presented that the fibers and cells possess surface potentials which are variable with the temperature and possibly also with the moisture. These electrical potentials determine the strength of the paper due to their attraction on the water film present between adjacent fibres and cells.

If I may be permitted to draw certain comparisons between your work and my work, it is remarkable how close your curves approach mine, to such a degree that I feel it admissible to assume that variations in your electrical curves can in part be traced back to the changes in the surface potentials of the fibers and cells.

I would be greatly obliged to you for an exchange of opinions over these questions and am of course glad to give you any further information on the subject.

Most respectfully,
A. BASBERG

I have attempted to find a copy of this paper in this country but have not been able to do so. I have answered the letter requesting a copy of the paper but have suggested that the sudden changes in the electrical characteristics of impregnated cable papers which occur around 50 deg C appear to be more a property of the impregnating compound rather than the paper itself.

I have also stated that the minimum point of the V- or U-curve which frequently occurs when the power is plotted as a function of temperature is due to the fact that the power loss in the paper may decrease with temperature and that in the compound may increase with temperature. These characteristics are shown in the paper "Fundamental Properties of Impregnated Paper" by J. B. Whitehead and W. B. Kouwenhoven, TRANS. A.I.E.E., v. 50, 1931, p. 699–704. An analysis of this type of characteristic together with the explanation by Hochstädter appears on p. 705 in my discussion of the foregoing paper.

Also the separate effects of oil and paper appear in Fig. 21 of the paper "Predetermination of the A-C Characteristics of Dielectrics" by J. B. Whitehead and Alfredo Banos, Jr., TRANS. A.I.E.E., v. 51, 1932, p. 402. From the data which I have available, I am therefore inclined to attribute such variations to the combined effects of the paper and compound, although I believe that any new theory, such as the one presented should be carefully considered.

Very truly yours,
C. L. DAWES (A'12, M'15)
(Harvard University,
Cambridge, Mass.)

Excitation and Ionization in Gases

To the Editor:

A pictorial representation of what is supposed to take place during excitation and ionization in gases may be useful in conveying to the reader an explanation of these actions. Further, the use of pictures is of assistance in impressing these ideas on the memory. Such a pictorial representation is given in the sketches of Figs. 1 to 19. The first figure in the group gives the notation which is followed throughout. The nucleus (shown as a circle with a plus sign in it) represents the proton and all the internal electrons which do not take part in the action being illustrated.

Information on the subject of excitation and ionization in gases was given in "Electric Discharges in Gases" by Dr. Lewi Tonks in ELECTRICAL ENGINEERING for February 1934, p. 239–43. Although this paper is much more scientific and informative, I believe that young engineers may get something out of such "primer pictures" as given in this letter, when becoming acquainted with the subject for the first time.

Electricity passing through a gas does not obey the same laws that it does in the case of passing through metallic conductors. The process seems to be a very complicated one and there are certain phenomena which are observed such as the emission of light, and effects of external agents such as sources of light on the conductivity of the gas, that make it essential that special study be given the subject. The group of figures shown in Figs. 3 to 19 is intended to illustrate some of the possible atomic processes. This group of figures is by no means complete, ionization by chemical processes, and by temperature, etc., having been omitted. The action in some of the pictures is supposed to take place in 2 or more steps; these steps are described in the picture title, and the reader is asked to let his imagination fill in the essential gaps in the story.

It must not be inferred from the figures that we claim the electron to be spherical or of any particular shape, or that a metastable atom has an electron moving along a zigzag path; these diagrams simply illustrate processes making them more tangible to the student. "Structure of Atoms and Molecules" by M. L. Huggins in ELECTRICAL ENGINEERING for June 1934, p. 851–6, and "A Chart of Consecutive Sets of Electronic Orbits within Atoms of Chemical Elements" by V. Karapetoff in the *Journal* of the Franklin Institute, v. 210, 1930, p. 609 may be referred to for information on the shape of the atoms and molecules.

Some sources of ionization in gases may be found, conveniently arranged in a table, on p. 128 of "Nature of a Gas" by L. B. Loeb (John Wiley & Sons).

At Professor V. Karapetoff's suggestion I prepared a similar set of figures to be used in connection with a course given at Cornell University.

It is suggested that in the remaining articles of the science series for engineers, which is appearing month-by-month in ELECTRICAL ENGINEERING, authors do not hesitate to use such "picture" stories in conveying ideas which they wish to impress upon the memory.

Very truly yours,

HARRY SOHON (A'28)

(Instructor in Elec. Engg., Cornell Univ., Ithaca, N. Y.)

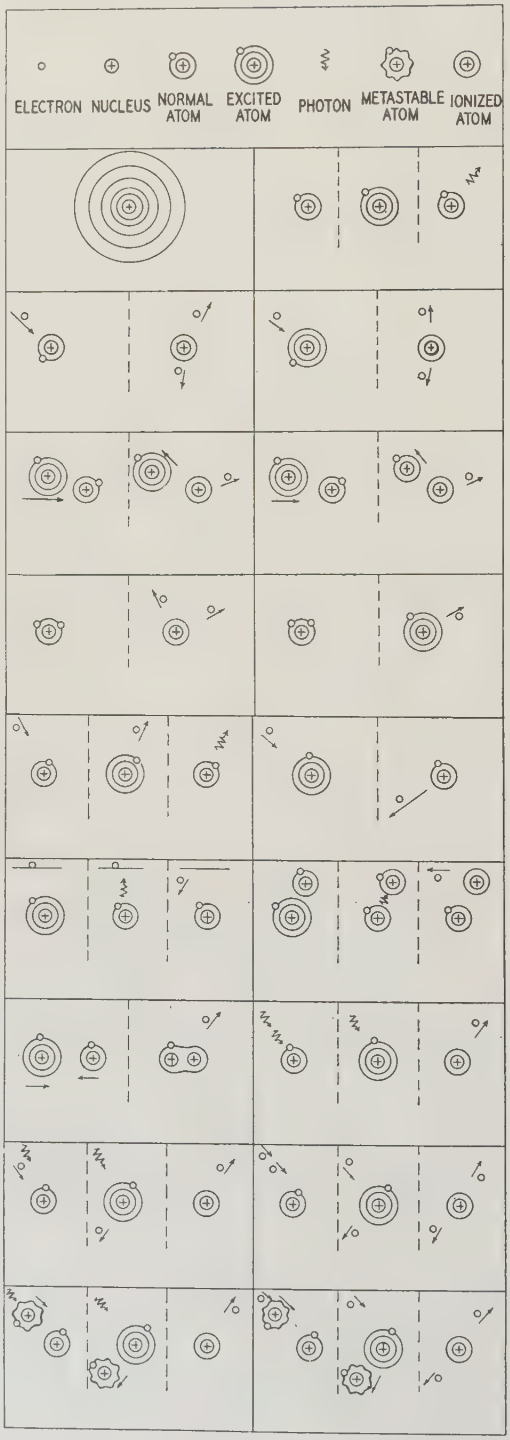


Fig. 1. Nomenclature

Fig. 2. Excitation potentials or energy levels

Fig. 3. Atom becomes excited, emits photon and returns to normal

Fig. 4. Electron strikes normal atom and ionizes it

Fig. 5. Electron strikes excited atom and ionizes it

Fig. 6. Excited atom strikes normal atom and ionizes it

Fig. 7. Excited atom strikes normal atom ionizing it, and returns to normal

Fig. 8. A normal atom may lose two electrons

Fig. 9. A normal atom may lose one electron and have another move to an upper level

Fig. 10. Electron strikes normal atom and excites it. The atom emits photon and returns to normal

Fig. 11. Collision of the second kind. Electron strikes excited atom and rebounds at increased velocity as atom returns to normal

Fig. 12. Excited atom returns to normal emitting photon which knocks an electron from solid surface

Fig. 13. Excited atom returns to normal emitting photon which ionizes another atom

Fig. 14. Excited atom collides with normal atom forming ionized molecule

Fig. 15. Ionization in two steps. One photon excites atom, and second photon ionizes it

Fig. 16. Ionization in two steps. Electron excites atom, and photon ionizes it

Fig. 17. Ionization in two steps. One electron excites atom and second electron ionizes it

Fig. 18. Ionization in two steps. Metastable atom excites normal atom and photon ionizes the latter

Fig. 19. Ionization in two steps. Metastable atom excites normal atom and electron ionizes the latter

Personal Items

JOSEPH SLEPIAN (A'17, F'27) consulting research engineer, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., and his co-author L. R. LUDWIG (A'28) have been awarded the 1933 A.I.E.E. national prize for best paper in theory and research for their contribution "A New Method for Initiating the Cathode of an Arc." Doctor Slepian was born at Boston in 1891, and received the degrees of A.B., A.M., and Ph.D. from Harvard, the last in 1913. After a year of study in Germany and Paris he was an instructor in mathematics at Cornell University until he entered the student course of the Westinghouse company in 1916. He joined the research department in 1917, shortly thereafter being given charge of the development of electrolytic condensers. In 1921 he devised the autovalve lightning arrester, and as a result of his researches on arcs he later produced the deion circuit breaker. Doctor Slepian holds numerous patents and has written many Institute papers. He is at the present time serving on 3 Institute committees, being chairman of the electrophysics committee.

L. R. LUDWIG (A'28) an electrical engineer for the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., and his co-author JOSEPH SLEPIAN (A'17, F'27) have been awarded the 1933 A.I.E.E. national prize for best paper in theory and research for their contribution "A New Method for Initiating the Cathode of an Arc." Mr. Ludwig was born at Kansas City, Mo., in 1904 and received the degree of B.S. from the University of Illinois in 1925. Following graduation he entered the electrical design school of the Westinghouse company and later became assistant to the chief electrical engineer. In 1928 he entered the railway motor engineering department, and in 1929 he received the Lamme memorial scholarship; during 1929–30 he was a graduate student at the University of Berlin. Since 1931 Mr. Ludwig has been associated with Doctor Slepian in the research department. He has prepared several Institute papers.

T. B. WAGNER (Enrolled Student) Portland, Ore., has been awarded the 1933 A.I.E.E. national prize for Branch paper for his paper "A Universal Measuring Instrument for Communication Circuits." Mr. Wagner received the degree of B.S. in electrical engineering from Oregon State College in 1933, and the degree of M.S. in electrical engineering in 1934. He was active in communication work while at college, being radio operator during 1932–34 at station KOAC, which is a one-kilowatt broadcast transmitter. He also built, repaired, and installed radio and other communication equipment at the college, and during 1933–34 he was assistant to A. L. ALBERT (A'27), associate professor of electrical engineering. He is a member of Sigma Pi Sigma and of Eta Kappa Nu, and joined the student branch of the Institute in 1930.

C. H. WILLIS (A'22, M'28) associate professor of electrical engineering, Princeton University, Princeton, N. J., has received honorable mention in the 1933 A.I.E.E. national prize award for best paper in theory and research for his paper "Amplifications of Harmonic Commutation for Thyratron Inverters and Rectifiers." Doctor Willis was born in Culpeper County, Va., in 1893. He received the degrees of B.A. from the University of Richmond in 1914 and B.S. in Engineering from Johns Hopkins University in 1916. He entered the cadet course of the New York Edison Company, but served in the Signal Corps during the war, being commissioned second lieutenant in 1918, and remaining with the army of occupation until 1919. From then until 1925 he was in the physics department of the University of Richmond, with a year of graduate study, 1922–23, at Johns Hopkins University, from which he received the degree of Ph.D. after an additional year of study there in 1926. He then became assistant professor of electrical engineering at Princeton University, and has been associate professor since 1929. During this time he has spent 2 leaves of absence in the research laboratory of the General Electric Company in Schenectady, N. Y. He is at present on 2 Institute committees.

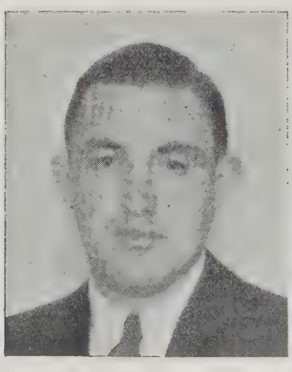
B. W. KENDALL (M'18, F'29) toll transmission engineer, Bell Telephone Laboratories, Inc., New York, N. Y., with his co-author A. B. CLARK (M'19, F'30) has received honorable mention in the award of the 1933 A.I.E.E. national prize for best paper in theory and research for the paper "Carrier in Cable." Mr. Kendall was born in Gardner, Mass., in 1883, and graduated from Massachusetts Institute of Technology in 1906 with the degree of B.S. Following graduate study in physics at Columbia University, New York, N. Y., he became an instructor there, and entered the research laboratory of the Western Electric Company in 1913. At this time his work was principally on telephone repeaters, but in 1915 he devoted a year to radio apparatus. In 1919 he was a member of a group sent to France to study a project for a telephone cable to connect Paris with Alsace and Lorraine. Upon his return he was given charge of toll development in the Western Electric Company and later in the Bell Telephone Laboratories. The work described in several Institute papers has been done in his department. Mr. Kendall is a member of the American Physical Society, the New York Electrical Society, and the Telephone Pioneers of America.

G. B. SCHLEICHER (A'20) technical assistant, meter division, Philadelphia Electric Company, Philadelphia, Pa., has received honorable mention in the 1933 A.I.E.E. national prize awards for initial paper for his contribution "Compensating Metering in Theory and Practice." Mr. Schleicher was born at Hamburg, Germany, and came to the United States in 1909. He graduated from the electrical construction course of the Philadelphia Trades School in 1915 and from Drexel Institute, Philadelphia, in 1919. From 1915 to 1917 he was employed by Leeds and Northrup Company, Philadelphia, for experimental work on electric resistance furnaces, and since 1917 he has been in the testing section and meter division of the Philadelphia Electric Company. Mr. Schleicher has prepared 2 papers for technical publications, and is the inventor of a compensating meter. He is secretary of the Philadelphia Society of Metermen and a member of the Pennsylvania Electric Association, and was awarded the silver medal for distinguished service rendered as a member of the International Jury of Awards, Sesqui-Centennial Exposition, Philadelphia, 1926.

A. B. CLARK (M'19, F'30) toll transmission engineer, American Telephone and Telegraph Company, New York, N. Y., with his co-author B. W. KENDALL (M'18, F'29) has received honorable mention in the award of the 1933 A.I.E.E. national prize for best paper in theory and research, for the paper "Carrier in Cable." Mr. Clark was born in Clay Centre, Ohio, in 1890. In 1911 he graduated from the University of Michigan with the degree of B.E.E. In that year he entered the engineering department of the company, and in 1919 took charge of a section of the department of development and research. He has been in this department since that

L. R. LUDWIG

T. B. WAGNER



JOSEPH SLEPIAN

W. J. MOULTON-REDWOOD

C. L. DAWES

P. H. HUMPHRIES

R. F. EDGAR

time, and is the inventor of a number of devices and systems, for the most part pertaining to long distance telephone transmission. He has written several papers on various developments. Mr. Clark is also a fellow of the Acoustical Society of America and a member of the American Association for the Advancement of Science.

C. L. Dawes (A'12, M'15) associate professor of electrical engineering, Harvard University, Cambridge, Mass., has been awarded the 1933 A.I.E.E. North Eastern District prize for best paper jointly with his co-author P. H. Humphries (A'26) for their paper "The Electrical Characteristics of Impregnated Cable Papers." Professor Dawes was born at Somerville, Mass., in 1886 and received the degree of B.S. in electrical engineering from the Massachusetts Institute of Technology in 1909, where he remained as an assistant until 1911, when he became an instructor at Harvard. During the summers of these 2 years he worked for the Edison Electric Illuminating Company of Boston, Mass. In 1913–14–15 he was professor of electrical engineering at the United States Naval Academy on leaves of absence, and assisted in establishing the post graduate school for naval officers. The schools of Harvard and Massachusetts Institute of Technology were combined from 1915 to 1919, and during the war Professor Dawes was an instructor in electrical engineering and radiotelegraphy at the Naval Aviation Ground School at M.I.T. He was appointed assistant professor of electrical engineering at Harvard in 1919, and became associate professor in 1931. He has been connected with a number of electrical industries for some years in a consulting capacity, and has contributed several papers on engineering and educational subjects.

P. H. Humphries (A'26) assistant professor of electrical engineering, Tulane University, New Orleans, La., shares with his co-author C. L. Dawes (A'12, M'15) the award of the Institute's North Eastern District 1933 prize for best paper, their contribution being "The Electrical Characteristics of Impregnated Cable Papers." Professor Humphries was born at Inlet, Va., in 1903. In 1917 he moved to Boston, Mass., and graduated from Boston Latin School in 1921, in which year he entered the electrical engineering course of Harvard University. He graduated with honors in 1925, after which he spent 1 year as an assistant and 2 years as an instructor in the electrical engineering department. He received the degree of M.S. in electrical engineering in 1928, and was a research associate until 1930, when he was appointed assistant professor of electrical engineering at Tulane University. In addition to teaching he is engaged in research upon the electrical characteristics of ionized gas films and related problems in high voltage engineering. He has been co-author with Professor Dawes of several previous papers. Professor Humphries is a member of the Society for the Promotion of Engineering Education, American Association of University Professors, Sigma Xi, Harvard Engineering Society, and American Academy of Political and Social Sciences.

R. F. Edgar (A'29) General Electric Company, Schenectady, N. Y., has received the 1933 A.I.E.E. North Eastern District prize for initial paper for his paper "Loss Characteristics of Silicon Steel at 60 Cycles With D-C Excitation." Mr. Edgar is a native of the Middle West, having been born on a farm near Detroit, Mich., in 1905. His family subsequently moved to a wheat ranch in North Dakota, and he attended school and college in Minneapolis, Minn., receiving the degree of B.S. in electrical engineering from the University of Minnesota in 1927. He remained 2 years longer, engaging in teaching and graduate work, and received the degree of M.S. in electrical engineering in 1929. In the summer of that year he came to Schenectady to enter the test course of the General Electric Company, and in the fall of 1930 was transferred to the magnetic division of the general engineering laboratory. Mr. Edgar is a member of Eta Kappa Nu, Tau Beta Pi, and Sigma Xi.

E. L. Angell (A'34) meter department, Narragansett Electric Company, Providence, R. I., has been awarded jointly with his co-author H. L. Anderson (A'34) the 1933 A.I.E.E. North Eastern District prize for Branch paper for their paper "A Study of Mercury Switches." Mr. Angell was born at Woonsocket, R. I., in 1912 and received the degree of B.S. in engineering from Brown University in 1933. While in college he specialized in the field of electrical engineering and was a student member at the time the paper was written.

H. L. Anderson (A'34) meter department, Narragansett Electric Company, Providence, R. I., shares with E. L. Angell (A'34) the 1933 A.I.E.E. North Eastern District prize for Branch paper for their paper "A Study of Mercury Switches." Mr. Anderson was born at Cranston, R. I., in 1911. He received the degree of B.S. in engineering from Brown University, Providence, in 1933, having specialized in electrical engineering. He was an Enrolled Student at the time the paper was written.

W. J. Moulton-Redwood (A'20) consulting and appraisal engineer, Toronto, Ont., Canada, has been awarded the 1933 A.I.E.E. Canada District prize for best paper for his paper "Valuation and Depreciation." Mr. Moulton-Redwood was born at London, England, in 1893 and received his education there. After some experience in an electrical laboratory and as a draftsman in a foundry he came to the United States in 1914 and worked on construction. With the outbreak of the war he was commissioned in the Canadian Expeditionary Force, and was seriously wounded at Cambrai in 1918. He returned to Canada in 1920 and was employed by the Canadian National Carbon Company and the Prest-O-Lite Company. He has also been employed by General Motors Corporation in New Zealand, and on the valuation staff of the Canadian National Railways. His most recent work of note has been the appraisal of the physical assets of the General Steel Works for the whole of Canada. He is now a registered professional engineer of the Providence of Ontario.

C. F. Himes (A'34) electrical department, Stanolind Pipe Line Company, Haven, Kan., has been awarded the 1933 A.I.E.E. North Eastern District prize for Branch paper for his paper "Aviation Radio." Mr. Himes was born at Edmond, Okla., in 1909. On completion of high school he entered the State Teachers' College in Edmond, from which he received a life certificate in 1928. After another year of study of courses which would apply in engineering he entered Oklahoma Agricultural and Me-

chanical College at Stillwater, Okla., from which he received the degree of B.S. in electrical engineering in 1933, having returned to the State Teachers' College in 1931 to receive the degree of B.S. in education. He was interested in aviation and during college was co-organizer of a glider club in 1930, engaging also in other campus activities. Before his present employment he was a teacher in the Mound Valley Public School at Hominy, Okla.

C. M. Davis (A'08) formerly assistant engineer of the transportation department, General Electric Company, Erie, Pa., has been appointed engineer in charge of that department. Mr. Davis is a native of Chicago, Ill., and was graduated from the University of Michigan in 1908. He received his master's degree at Union College in 1909, and entered the test department of the General Electric Company at Schenectady, N. Y., in that year. Following some time in the consulting engineering department under Dr. C. P. Steinmetz he entered the railway engineering department in 1913, and became assistant engineer in 1930, the department meanwhile having been moved to Erie. In 1924 he was sent to Australia in connection with the South Wales Government Railway electrification.

A. L. Powell (A'13, F'26) supervising engineer, incandescent lamp department, General Electric Company, New York, N. Y., has been elected president of the Illuminating Engineering Society for the year 1934–35. Mr. Powell is an internationally known authority on illumination design and application, and as lighting consultant for the Rockefeller Center development originated many of the ingenious effects in the Radio City Music Hall and other buildings. He has been with the General Electric Company since 1910, and is a member of the U.S. National Committee of the International Commission on Illumination. He is at present serving the Institute on the board of examiners and on the committee on the production and application of light.

L. W. Chubb (A'09, F'21) director of the research laboratories of the Westinghouse Electric and Manufacturing Company, has been awarded the Lamme medal of Ohio State University, the presentation taking place on June 11, 1934. Except for a short period with the Radio-Victor Corporation of America, he has served the same company continuously since his graduation from Ohio State. Mr. Chubb has been active in standardization work and has twice served as a delegate of the International Electrotechnical Commission. He has served on numerous committees of the Institute since 1914. His development work has resulted in his being awarded some 200 patents in the electrical, mechanical, chemical, electrochemical, and welding fields.

T. W. Carraway (A'21, M'32) former manager of the Unit Cooler Division of the Grinnell Company, resigned that position on January 1, 1934, to head the Carraway Engineering Company, although he retains identity with the former company in a different capacity. Mr. Carraway has designed and supervised the installation of about 100 plants of various sizes during the past 10 years, and has designed a number of automatic controls. While in the Army he installed the 2 largest plants of their kind on the American continent, at Camp Holabird, Baltimore, and Camp Normoyle, San Antonio.

J. L. Holton (A'30) division engineer, New York and Queens Electric Light and Power Company, New York, N. Y., has been awarded a James H. McGraw prize by the Edison Electric Institute for his paper "Engineering Necessary in the Development of an Extensive Low Voltage Network," which was judged one of the 3 most meritorious papers on any engineering or technical subjects relating to the light and power industry.

C. E. Tullar (A'22, M'31) manager of the patent department of the General Electric Company, Schenectady, N. Y., has been elected a vice president in charge of that department. Mr. Tullar has been with the company since 1919, having previously been in the U.S. Patent Office. He is a member of the bar of the Supreme Court and the Court of Appeals of the District of Columbia, and of the bar of the Supreme Court of the United States.

H. L. Andrews (A'16, M'26) former engineer in the transportation department of the General Electric Company, Erie, Pa., has been elected a vice president in charge of the activities connected with the electrification of steam railroads, and such other duties as may be assigned to him by the president. Mr. Andrews entered the testing department in 1910 and has been engineer of the transportation department since 1929.

E. B. Meyer (A'05, F'27, and vice president) vice president, United Engineers and Constructors, Inc., Newark, N. J., has been elected first vice president of the New York Electrical Society. Mr. Meyer has been active for many years in Institute affairs and has served the Institute in many important capacities, including the vice presidency for District No. 3 from which he retired Aug. 1, 1934.

D. D. Smalley (A'20, M'33) distribution superintendent of the Midland Counties Public Service Corp., Santa Maria, Calif., has been appointed general superintendent of the San Joaquin Light and Power Corporation, to succeed E. A. Quinn (M'15). Mr. Smalley has been with the San Joaquin and Midland Counties organizations since 1911. He will continue to supervise the operations of the Midland subsidiary.

A. W. Berresford (A'94, F'14, member for life, and past president) has resigned as managing director of the National Electrical Manufacturers Association whose activities he has guided for 5 years. Mr. Berresford was president of the Institute 1920–21, having served previously as a manager and as a vice president. A biographical sketch of Mr. Berresford is given on p. 804 of Electrical Engineering, May 1934.

A. L. POWELL

S. O. Schamberger (A'21) hydraulic engineer, New York Power and Light Company, Albany, N. Y., has been awarded a James H. McGraw prize by the Edison Electric Institute for his paper "Hydro Station Operation With Minimum Loss," which was judged one of the 3 most meritorious papers on any engineering or technical subjects relating to the light and power industry.

I. E. Moultrop (A'10, F'29) chief engineer and superintendent of construction bureau, Edison Electric Illuminating Company of Boston, Mass., is a member of the executive committee of the Engineering Societies of New England. He has served on numerous Institute committees and is now a member of the committees on power generation and automatic stations.

H. H. Spencer (A'25) formerly assistant engineer of the New England Power Construction Co., Boston, Mass., has joined the Raytheon Manufacturing Corporation, Newton, Mass., where he will specialize in problems of product development. Mr. Spencer is a member of the committee on power transmission and distribution, having served since 1931.

William Fondiller (M'15, F'26) assistant director of apparatus development, Bell Telephone Laboratories, New York, N. Y., has accepted the invitation of the Columbia University school of engineering to act as research associate in the department of industrial engineering. Mr. Fondiller served on the electrophysics committee of the Institute, 1922–24.

H. S. Vassar (A'06, M'18) laboratory engineer, Public Service Electric and Gas Company, Irvington, N. J., has been elected a vice president of the American Society for Testing Materials. Mr. Vassar served the Institute on the electrophysics committee, 1920–21, and on the instruments and measurements committee, 1920 and 1922–25.

R. C. Muir (A'08, M'19) manager of the engineering department of the General Electric Company, Schenectady, N. Y., has been elected a vice president in charge of

the engineering department. Mr. Muir has been with the General Electric Company since he entered the student course in 1905, most of the time in the industrial engineering department.

L. V. Sutton (A'11) president and general manager of the Carolina Power and Light Company, Raleigh, N. C., has been elected second vice president of the Southeastern Electric Exchange, which is the successor to the Southeastern geographic division of the former National Electric Light Association.

C. C. Driscoll (A'28) formerly in the frequency change department of the Consumers Power Company, Grand Rapids, Mich., left recently to return to his home in Australia, where he will be associated with K. H. Milne (A'26) as an engineer with the Adelaide Electric Supply Company, Adelaide, Australia.

E. O. Shreve (A'08) former assistant vice president, has been elected vice president in association with Vice President J. G. Barry (A'03) in the commercial activities of the apparatus and supply business of the General Electric Company, Schenectady, N. Y. He has been associated with the company since 1904.

Bancroft Gherardi (A'95, M'04, F'12, past president, and member for life) vice president and chief engineer, American Telephone and Telegraph Company, New York, N. Y., has been appointed a representative of the Institute on the John Fritz Medal board of award, to succeed the late W. S. Lee.

E. A. Quinn (M'15) general superintendent of the San Joaquin Light and Power Corporation, Fresno, Calif., has resigned on account of ill health. Mr. Quinn has been a member of the San Joaquin organization since 1914, during most of that time occupying the post from which he resigned.

R. D. Lillibridge (A'02, M'19) former president of Ray D. Lillibridge, Inc., has recently established an advertising business under the name of Lillibridge, Adamson, and Kitchen. Mr. Lillibridge has been engaged in the advertising of electrical and other products for 25 years.

W. O. Batchelder (A'08) central district manager of the General Electric Company, Chicago, Ill., has been elected a commercial vice president in charge of the commercial activities of that district. Mr. Batchelder has served previously in the Minneapolis, Butte, and Detroit offices.

L. A. S. Wood (M'24) manager, exterior lighting section, Westinghouse Electric and Manufacturing Company, Cleveland, Ohio, has been elected a vice president of the Illuminating Engineering Society.

R. H. Hughes (A'20, M'30) assistant vice president, New York Telephone Company, New York, N. Y., has been elected second vice president of the New York Electrical Society.

Obituary

Harris Joseph Ryan (A'87, M'95, F'23, past president, and member for life), emeritus professor of electrical engineering, Leland Stanford, Jr., University, Palo Alto, Calif., died on July 3, 1934, from a heart attack. He was born at Powells Valley, Pa., January 8, 1866, and received his early education at Baltimore City College and Lebanon Valley College. In 1883 he entered Cornell University, Ithaca, N. Y., as a member of the first class in the newly organized course in electrical engineering, for which the equipment consisted of that of the physics laboratory with the addition of a d-c generator made by W. A. Anthony, president of the Institute, 1890–91. Following his graduation in 1887, Professor Ryan spent 2 years with the Western Engineering Company, Lincoln, Neb., and then returned to Cornell to become an instructor in the physics department. During 1889 he and Ernest Merritt, who later became a president of the American Physical Society, prepared a paper on transformers which was presented before a meeting of the Institute in December of that year and published in the Proceedings the following month. It was this paper which first brought him to prominence. He was appointed assistant professor of electrical engineering in 1890, associate professor in 1892, and professor and head of the department in 1895 at the age of only 29. One of his important works while at Cornell was the development of the pole face winding and the principle of the interpole which counterbalanced the effects of armature reaction in d-c machines. He also became interested in high voltage transmission, and succeeded in disproving the then common belief that 40,000 volts was the maximum economical transmission voltage. In the course of this work he constructed an air insulated transformer for 90,000 volts which was in use in the laboratory for many years afterward. The results were presented in a paper in 1904. About 1900 he started a series of studies of the cathode ray tube, which he applied to the measurement of voltage and current. When the Ithaca Section of the Institute was authorized in 1902, Professor Ryan became its first chairman, a position which he held until 1905, when he went to Stanford University to become professor of electrical engineering in charge of the department there. In addition to his other work he was consulting engineer for the Los Angeles Aqueduct Power Bureau from 1909 to 1923. He continued his researches in power transmission, and in recognition of his work the university built a high voltage laboratory in 1913 in which the principal item of equipment was a 350,000-volt transformer. Here Professor Ryan constructed a 60,000-cycle oscillator for use in the study of insulator flashover, and in 1916 devised a potentiometer for measuring the potential across each unit in a suspension string. For the year 1918–19 he was director of the supersonics laboratory of the National Research Council, Pasadena, Calif. As voltages continued going higher, he was frequently called on as a consultant, and devoted much time to the study of corona formation on conductors. He was elected president of the Institute for the year 1923–24, and in 1925 was awarded the degree of doctor of laws by the University of California, during which year he was also awarded the Edison Medal of the Institute. The following year the Harris J. Ryan high voltage laboratory at Stanford University was opened. The building and equipment were gifts from manufacturing and power companies, while the university provided the land, including a strip suitable for a 7-mile experimental transmission line. He became emeritus professor in 1931. He was a manager of the Institute, 1893–96, and a vice president, 1896–98, as well as president. Among the 11 committees on which he served were the Edison Medal, the John Fritz Medal board of award, and the Coffin fellowship and research fund; he also served on the United States national committee of the International Electrotechnical Commission. He was judge, board of awards, at the World's Fair, Chicago, 1893; United States delegate to the International Electrical Congress, St. Louis, 1904; and member of the jury, Panama Pacific International Exposition, San Francisco, 1915. He was a member of The American Society of Mechanical Engineers, the American Physical Society, the American Association for the Advancement of Science, the National Academy of Sciences, the Institute of Radio Engineers, Phi Kappa Psi, and Sigma Xi.

Edward Marriott Hewlett (A'91, F'17, and member for life) consulting engineer, Schenectady, N. Y., died May 24, 1934, after an illness of a few days. He was born at Cold Spring Harbor, N. Y., Sept. 14, 1866, and was educated in private schools and by private study in civil and mechanical engineering and physics. From 1884 to 1890 he was general manager and civil engineer of the Cascade Town Improvement Company of Cascade, Col. In 1888 he surveyed and laid out the road to the top of Pike's Peak. He began his electrical career in 1890 with the Thomson-Houston Electric Company in Lynn, Mass., which later became the General Electric Company. He was appointed head of the switchgear department when it was organized in 1898, and from 1907 until 1927 he was engineer of this department. At this time he became consulting engineer, and retired from active service in 1931. Mr. Hewlett was responsible for many important developments and held about 160 patents. Among the projects on which he worked were the illumination of the Statue of Liberty, the design of switchboards for several railway electrifications, notably the Interborough Rapid Transit system and the New York Central Railroad terminal electrification, both in New York. He assisted in the development of the oil switch and the suspension insulator, and designed the control apparatus for operating the locks on the Panama Canal. He also proposed and designed the modern fire control system of the United States Navy, and during the World War was chief engineer of the Navy Experimental Station at New London, Conn. Mr. Hewlett served the Institute on the protective devices committee from 1916 until 1922.

Frederick George Proutt (A'03, M'04) onsulting engineer and chairman of the City Board of Water Commissioners of Memphis, Tenn., died May 27, 1934, fter an illness of 6 months. Mr. Proutt vas born at Bowmanville, Ont., Canada, n November 27, 1870. He was employed y the Canadian Bell Telephone Company or miscellaneous work in 1877, but he left n 1890 to become superintendent of the Bowmanville Electric Light Company and years later entered the student course of he General Electric Company at Lynn, Mass. Upon completion of the course in 894 he became chief electrician of the Malden Electric Company, Malden, Mass., nd in 1897 joined the Memphis Light and Power Company, Memphis, Tenn., in the ame capacity, where he was responsible for ebuilding the plant. For 2 years following 1906 he was general manager of the treet railway and electric and gas plant at ackson, Miss., after which he returned to Memphis and opened his office as a consulting engineer. He worked as consultant or many utilities, and during the war was n engineer and appraiser for the War Finance Corporation. Since 1920 he had been chairman of the board of water commissioners. Mr. Proutt was a charter member of the Engineers' Club of Memphis, of which he was its first president, and a charter member of the Memphis Section of the Institute. He was also a member of The American Institute of Mechanical Engineers.

Roy William Gray (A'03, F'28) formerly principal telephone and telegraph engineer of the Interstate Commerce Commission, Washington, D. C., died at Washington, April 28, 1934. He was born at Bradford, Iowa, in 1875. Following 3 years of study at what is now the California Institute of Technology, Pasadena, he became engaged with Wybre and Lawrence Company, Los Angeles, Calif., contracting electrical engineers, in 1896, as draftsman. Between 1898 and 1910 he was with the Bell Telephone system, being employed at different times in the states of California, Oregon, Washington, Nevada, and Arizona, acquiring a wide experience in telephone plant construction and operation. In 1910 he joined the organization of the Western Union Telegraph Company, becoming division plant superintendent of the Pacific division in charge of design, construction, and operation. In 1914 he became senior telephone and telegraph engineer for the Pacific district of the Bureau of Valuation of the Interstate Commerce Commission. In 1921 he became telephone and telegraph engineer of the Interstate Commerce Commission at Washington, D. C., in charge of the telephone and telegraph branch of the Bureau of Valuation. During 1913 and 1914 Mr. Gray served as a member of the joint committee on inductive interference of the Railroad Commission of California, and a member of its subcommittees on tests and on program.

Edward Dubois Mathey (A'07, F'19), New York, N. Y., died May 13, 1934, after a prolonged illness. He was born at Cranford, N. J., August 22, 1873, and graduated from Stevens Institute of Technology in 1894 with the degree of M.E. His first work was as draftsman for street railway companies, designing the west side substations for the Manhattan Elevated Railway Company, New York, N. Y., in 1901. In 1902 he joined Westinghouse Church Kerr and Company, New York, where he remained until 1917. During this time he was in charge of electrical design of the Pennsylvania Railroad power station in Long Island City, N. Y., and of substations of the Long Island Railroad. He was also engineer of electrical work for several power installations. In 1917 he became electrical engineer in charge of the electrical division of Air Nitrates Corporation, agents for the United States government for the design, construction, and operation of plants for nitrate production. His work included plants at Muscle Shoals, Ala., Toledo, Ohio, and Cincinnati, Ohio. The last 2 were not completed because of the signing of the armistice. He continued the same type of work after the war, joining the American Cyanamid Company, New York, as electrical engineer, which involved oven, electric furnace, power, and other electrical and electrochemical operations.

Harry Allen Currie (A'03, F'29) electrical engineer, New York Central Railroad Company, New York, N. Y., died suddenly on June 9, 1934, of angina pectoris. He was born at Maitland, Nova Scotia, on August 25, 1872. He attended high school at Halifax, Nova Scotia, and followed this with a course at Cooper Union, New York, N. Y., having also spent some time at sea. From 1894 to 1903 he was employed by the Brooklyn Heights Railway, Brooklyn, N. Y., in power house operation, electrification of elevated lines, and general maintenance of rolling stock. In 1903 he entered the service of the New York Central Railroad, where his first work was at Schenectady, N. Y., in connection with development for the electrification of that railroad. He was transferred to New York in 1906 to take charge of third rail installation, and the following year was appointed assistant electrical engineer, becoming electrical engineer in 1928. He was in charge of the electrical work for the improvements now nearing completion on the West Side, New York City, and was a consulting engineer for the electrification of the Cleveland (Ohio) Union Terminal. Mr. Currie was a member of the board of examiners 1930–34, and of the committee on transportation 1931–34.

Leonard P. Dickinson (A'07, M'28) professor of electrical engineering, University of Vermont, Burlington, Vt., died in the early part of June 1934. He was born at Hill, N. H., May 3, 1874. After receiving his degree in the electrical engineering course at Massachusetts Institute of Technology, Cambridge, Mass., in 1896, he worked for short periods for the American Telephone and Telegraph Company and the General Electric Company, and then began teaching in 1898. During the next few years he was an instructor at the University of Maine, Orono, Me.; Manual Training School, New Haven, Conn.; Armour Institute of Technology, Chicago, Ill; and Lafayette College, Easton, Pa. He became professor of physics and electrical engineering at Rhode Island State College, Kingston, R. I., in 1909, and remained there until 1919 when he went to Constantinople, now Istanbul, Turkey, as professor of electrical engineering at Robert College. He returned 2 years later to become professor of electrical engineering at the University of Vermont. In each of these last 3 he was head of the department. Professor Dickinson was a member of the Society for the Promotion of Engineering Education.

James Milne (M'33) electrical and mechanical engineer, City of Toronto, Ont., died suddenly on May 21, 1934. He was born in Scotland, January 29, 1865, and received his technical education at Gordons College, Aberdeen. From 1881 to 1886 he served an apprenticeship as a mechanical engineer, and in 1887 came to Canada, where he was employed by the Edison General Electric Company in Montreal. For 6 years following 1890 he was general superintendent of the Toronto Electric Light Company, after which he taught for 2 years in the Toronto Technical School. He then became general manager and chief engineer of The Underfeed Stoker Company, Toronto, and also engaged in consulting engineering. In 1906 he accepted the position of general superintendent of the British Columbia Electric Railway Company, Vancouver, B. C., which he left in 1910 to engage in consulting engineering in Vancouver, Windsor, Ont., and Toronto. He assumed his duties as engineer for the City of Toronto in 1914 and was so engaged until his death. Mr. Milne was a member of The American Society of Mechanical Engineers and of the Professional Engineers of Ontario.

Floyd Elliott Dellinger (A'26, M'33) overhead electrical engineer of the Los Angeles Gas and Electric Corporation, Los Angeles, Calif., died suddenly of a heart attack on June 8, 1934. He was born at Java Village, Wyoming County, N. Y. Starting with the Olean Electric Light and Power Company, Olean, N. Y., in 1898, he was afterward engaged in wiring with the Pan-American Exposition Company, Buffalo, N. Y., in 1901, and as a foreman of wiring and line construction with the General Machinery Company, Suffolk, Va., in 1902. He returned to Olean in that year as electrician with the Vacuum Oil Company and in 1905 joined the Nevada California Power Company for 4 years at Goldfield, Tonopah, and Manhattan, Nev., as wireman, foreman, and superintendent. In 1909 he entered the Los Angeles Gas and Electric Corporation as a meter tester, later becoming inspector, foreman, and overhead electrical engineer. Mr. Dellinger was a member of the Los Angeles Electric Club and the Pacific Coast Electrical Association. He served on the Institute's membership committee 1928–29 and was chairman of the Los Angeles Section 1932–33.

William Morton Scott (M'22) division superintendent, Utah Power and Light Company, Salt Lake City, Utah, died May 20, 1934, from heart trouble. His death occurred in Reno, Nev., while he was on a vacation trip to California. Mr. Scott was born at New Point, Ind., July 5, 1864. He studied a course in lighting and railways through the International Correspondence School, and went to Utah as a young man, entering the Union Power and Light Company in 1897. He became construction superintendent of lines 6 years later, and, absorbing additional responsibilities in the fast growing industry, was made superintendent of the Salt Lake division of the Utah Power and Light Company about 1914, in which position he was in charge of substations, electrical service, and line construction. During this time he handled many problems incident to the growth of the electrical industry in that territory. He was active in many organizations and was vice president of the Salt Lake Council of the Boy Scouts of America. At the time of his death Mr. Scott was secretary of the Utah Section of the Institute.

Hermann C. Henrici (M'23) president, Henrici, Lowry Engineering Company, Kansas City, Mo., died May 30, 1934, following an illness of several months' duration. He was born at Kansas City, Mo., in 1884, graduating from Massachusetts Institute of Technology in 1906. Upon graduation he entered the engineering department of the Missouri and Kansas Telephone Company, Kansas City. The following year he became a manager, holding this position until he left the company in 1909 for work in the W. T. Osborn Electric Company, contractors and engineers. In 1913 he joined the company of which he became president. In this firm he designed and supervised the installation of power plants and water works, and prepared appraisals and presented them before public utilities commissions in several midwestern states. Much of the work was for municipalities. He was a member of the American Society of Heating and Ventilating Engineers, the American Society of Refrigerating Engineers, and of the Engineers' Club.

Paul W. Ripple (A'04, M'13), The Connecticut Company, New Haven, Conn., died May 15, 1934. He was born at Orbisonia, Pa., May 8, 1877, and after completing high school studied electrical engineering through the International Correspondence Schools. He then was employed by the Westinghouse Electric and Manufacturing Company for 7 years, leaving in 1904 to accept a position as electrical engineer with the Lehigh Valley Railroad Company. Three years later he was employed by the Worcester Consolidated Street Railway Company, Worcester, Mass., where he remained until 1912, when he joined the Connecticut Company as chief engineer, having supervision of power equipment and rolling stock, including that of several subsidiary New England street railway companies.

Ralph Roberts Laxton (A'04, M'13) sales engineer, Westinghouse Electric and Manufacturing Company, Charlotte, N. C., died April 15, 1934. He was born at Morgantown, N. C., April 21, 1870, and attended high school there. He received private instruction in engineering and law. Following varied experience in railroad and power plant work he became assistant to the local manager of the General Electric Company in Atlanta, Ga., in 1903, and after a short period of supervisory work joined the Westinghouse organization in 1906, working in Atlanta and Charlotte offices.

George Martin McCarty (A'22, M'30) telephone engineer, American Telephone and Telegraph Company, New York, N. Y., died March 30, 1934. He was born at Norwich, N. Y., Sept. 2, 1881. He graduated from Brooklyn Polytechnic Institute in 1906, and entered the New York Telephone Company, where he was engaged in general design work. In 1912 he joined the A. T. and T. Co., where he was concerned with the design and layout of equipment of manual and dial apparatus. Lately he has supervised the investigation of new magnetic, insulating, contacting, and structural materials.

Membership

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before Aug. 31, 1934, or Oct. 31, 1934, if the applicant resides outside of the United States or Canada.

Aunen, H. J., Stone & Webster Engg. Corp., Lake Charles, La.
Barstow, J. MacD., Bell Tel. Lab., N. Y. City.
Beckwith, S., Metropolitan Water Dist. of Southern California, Los Angeles.
Boyce, H. A., Jr., Amer. Tel. & Tel. Co., Cleveland, Ohio.
Breen, F. J., Jr., Cincinnati Bell Tel. Co., Cincinnati, Ohio.
Clayton, W. R., City of Thomasville, Thomasville, Ga.
Day, I. F., U.S. Lighthouse Service, Portland, Ore.
Dunseath, H., Jr., Menlo Hotel, Oakland, Calif.
Healis, G. A., I-T-E Circuit Breaker Co., Philadelphia, Pa.
Kawecki, H. C., 1912 N. Damen Ave., Chicago, Ill.
Kettig, T. H., Southern Bell Tel. Co., Louisville, Ky.
Johnson, C. O. (Member), Bd. of Public Utilities, Jamestown, N. Y.
Johnston, E. F., N. Y. Hospital, N. Y. City.
LaBarr, W. W., Allis-Chalmers Mfg. Co., Los Angeles, Calif.
Langley, R. H. (Member), 165 Broadway, N. Y. City.
Leonard, M. G., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Love, W. S., Niagara Lockport & Ontario Power Co., Olean, N. Y.
Morrill, W., Virginia Elec. & Power Co., Williamsburg, Va.
Murray, C. S., Jr., N. Y. Edison Co., N. Y. City.
Myrick, E. B., Gen. Elec. Co., Louisville, Ky.
Noble, G., Mountain Park Collieries, Ltd., Alberta, Can.
Peck, C. E., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.
Philips, E. D., Chesapeake & Potomac Tel. Co., Washington, D. C.
Schuler, G. J., N. Y. Steam Corp., N. Y. City.
Van Vechten, G. B., Bklyn. Edison Co., Inc., Brooklyn, N. Y.

25 Domestic

Foreign

Claricia, P. M., Western Equip. & Supply Co., Manila, Philippines.
Harrap, G. V., North-Eastern Elec. Supply Co., Ltd., Dunston, Gateshead, Eng.
Jamora, L. L., Iloilo, Philippines.
Matto, R. N. (Member), Supply Centre, Srinagar Kashmir, India.
Ramakrishna, R., Tata Power Co., Ltd., Kalyan, India.

5 Foreign

Recommended for Transfer

The board of examiners, at its meeting of July 25, 1934, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Fellow

Dorsey, Herbert G., principal E.E., U.S. Coast & Geodetic Survey, Washington, D. C.

1 to Grade of Fellow

To Grade of Member

Bellaschi, Peter L., devpmt. and res. engr., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Brosnan, Thomas J., E.E., Buffalo, Niagara & Eastern Power Corp., Buffalo, N. Y.
Carlson, Edward, Jr., E.E., Blackstone Valley Gas & Elec. Co., Pawtucket, R. I.
Ewart, J. Norton, asst. elec. supt., C. R. Huntley Steam Stations of Buffalo Gen. Elec. Co., Buffalo, N. Y.
Faus, Harold T., devpmt. eng., Gen. Elec. Co., West Lynn, Mass.
Ferguson, Edward F., chief engr., Gustav Hirsch Organization, Columbus, Ohio.
Ferguson, Whitworth, vice president and E.E., Robertson Elec. Constr. Co., Buffalo, N. Y.
Fosdick, Ellery R., asst. engr., Public Service Commission, Olympia, Wash.
Grasser, Arthur P., E.E., Cleveland Elec. Illum. Co., Cleveland, Ohio.
MacDonald, Cecil J., asst. E.E., Susquehanna Collieries Co., Nanticoke, Pa.
McKinley, Victor L., asst. network engr., Louisville Gas & Elec. Co., Louisville, Ky.
Scanlon, J. Leo, elec. sales engr., J. Leo Scanlon Co., Buffalo, N. Y.
Scott, John Alexander, E.E., Gen. Elec. Co., Schenectady, N. Y.
Terman, Frederick E., assoc. prof. of E.E., Stanford University, Calif.
Wilde, Oscar A., asst. E.E., Sun Shipbuilding & Dry Dock Co., Chester, Pa.

15 to Grade of Member

Addresses Wanted

A list of members whose mail has been returned by the postal authorities is given below, with the address as it now appears on the Institute record. Any member knowing of corrections to these addresses will kindly communicate them at once to the office of the secretary at 33 West 39th St., New York, N. Y.

Clark, Merrill C., 161 Madison Ave., New York, N. Y.
Handley, Wilbur H., 4416 Loren Ave., Los Angeles, Calif.
McNitt, Donald P., 1009 First Natl. Life Bldg., St. Louis, Mo.
Mexal, J. Rene, 86–03 Britton Ave., Elmhurst, L. I., N. Y.
Miller, Frank D., Box 34, Yatesboro, Pa.
Moellendick, K. F., L. A. Automotive Works, 1010 Towne Ave., Los Angeles, Calif.
O'Handley, Joseph A. E., 579—61st St., Bklyn., N. Y.
Patton, Edgar P., Standish Arms, 169 Columbia Heights, Bklyn., N. Y.
Schultz, Carl H., 15 Cook St., Jersey City, N. J.
Stuntz, Hans, 106 Peck Ave., Newark, N. J.
Tamburello, G., 307 West 20th St., N. Y. City.
Thompson, B. F., Minas de Matahambre, Matahambre, Pinar Del Rio, Cuba.
Villegas, Lucio P., Tacoma General Hospital, Tacoma, Wash.
Wagoner, K. S., 320 Wisconsin, Oak Park, Ill.

14 Addresses Wanted

Engineering Literature

New Books in the Societies Library

Among the new books received at the Engineering Societies Library, New York, recently, are the following which have been selected because of their possible interest to the electrical engineer. Unless otherwise specified, books listed have been presented gratis by the publishers. The Institute assumes no responsibility for statements made in the following outlines, information for which is taken from the preface of the book in question.

KEMPE'S ENGINEER'S YEARBOOK of Formulae, Rules, Tables, Data & Memoranda for 1933–34. A compendium of Civil, Mech., Elec., Marine, Gas, Aero, Mine & Metallurgical Engg. Rev. by L. St. L. Pendred. 40th ed. Lond., Morgan Bros. (Publishers) Ltd., 1933. 2623 p., illus., 7x5 in., lea., 31s 6d. The current edition has undergone a very thorough revision, which undoubtedly will greatly increase its usefulness. All tables and general data have been revised, many illustrations replaced, obsolete material deleted and several entirely new articles added.

METALLURGY of IRON and STEEL. By B. Stoughton. 4 ed. N. Y. & Lond., McGraw-Hill Book Co., 1934. 559 p., illus., 9x6 in., cloth, $4.00. The new edition of this standard textbook and work of reference is practically a new book, having been entirely rewritten and rearranged. The subject is now presented largely from the historical point of view.

MUNICIPAL ELECTRIC PLANT MANAGERS, Their Selection, Training, Salaries, and Tenure, with a list of Municipally Owned Plants in the U.S. Pub. Administration Serv. Pub. 38. By E. C. Macmahon. Chicago, Pub. Administration Serv., 1934. 40 p., tables, 11x8 in., paper, $.60. This monograph is a study of the mode of selection, background, training and experience, salary, and tenure of managers of municipal electric plants. The study is based upon the practice of 690 American municipalities, about 36 per cent of the active municipal plants of the country.

NACHTRAG VI zum WERKSTOFFHANDBUCH "NICHTEISENMETALLE." Ed. by the Deutsche Gesellschaft für Metallkunde im Verein deutscher Ingenieure. DIN A 5, 33 p. Berlin, Beuth-Verlag, 1934. illus., 2.20 rm. This supplement completes the series, as originally contemplated. It includes papers on measuring instruments for mechanical testing, aluminum in the food industry, welding aluminum and its alloys, and methods of heat treating.

NATIONAL ELECTRICAL CODE HANDBOOK, based on the 1933 edition of the National Electrical Code. By A. L. Abbott. N. Y. & London, McGraw-Hill Book Co., 1934. 523 p., illus., 8x5 in., lea. In this handbook the provisions of the Code are grouped in a way that enables the user to ascertain quickly all the rules applying to any piece of work. Explanations, comments, and diagrams that clarify the rules have been added, with the aim of providing a helpful reference book for the engineer and contractor, and a systematic text for students. This edition is based on the 1933 Code.

PHYSICAL CONSTANTS. By W. H. J. Childs. Lond., Methuen & Co.; N. Y., E. P. Dutton & Co., 1934. 77 p., illus., 7x4 in., cloth, $1.20. Presents, in a volume which will go easily into the pocket, the constants which are in everyday use. Contains a large amount of information upon heat, light, electricity, magnetism, sound, and general physics, together with tables of logarithms and trigonometric functions.

PHYSICAL OPTICS. By R. W. Wood. 3 ed. New York, Macmillan Co., 1934. 846 p., illus., 9x6 in., cloth, $5.25. A clear, scholarly, and thoroughly modern treatment is afforded by this volume. As in preceding editions, the use of intricate mathematics has been avoided and physical pictures of the processes have been given. Special attention is given to describing experimental technique.

SIGNALS and SPEECH in ELECTRICAL COMMUNICATION. By J. Mills. N. Y., Harcourt, Brace & Co., 1934. 281 p., 8x5 in., cloth, $2.00. An attempt to give the general reader a few general principles, some illustrations, and as far as practicable a physical and philosophical background for the appraisal of present, and the imagination of future, systems or means of communication. The result is an unusual achievement; a clear, readable and accurate account of electrical systems of communication.

SPANNUNGSVERTEILUNG in KONSTRUKTIONSELEMENTEN. By E. Lehr. Berlin, VDI-Verlag, 1934. 64 p., illus., 12x8 in., paper, 7.50 rm. Special methods of investigation of the distribution of stresses in machinery by means of models, optical measurements, etc., have been developed, and numerous reports have been published which clarify the problem. These reports, however, are widely scattered and often understandable only to specialists. The present publication summarizes the results of these investigations in form for practical use.

TECHNIK GESCHICHTE. (Beiträge zur, Geschichte der Technik und Industrie, Bd. 22, 1933). Berlin, VDI-Verlag, 1933. 156 p., illus., 12x8 in., cloth, 12 rm. The new volume of this annual contains papers on many branches of industry. Early Alpine roads, transportation in the Middle Ages, pre-Christian foundry practice, the oldest use of iron, the earliest electric telegraph, the history of the windmill, and other topics are discussed by authorities.

Die TECHNISCHE ELEKTROLYSE WÄSSERIGER LÖSUNGEN, A.-Die technische Elektrometallurgie wässeriger Lösungen, Die GALVANOTECHNIK, by G. Elssner. (Handbuch der technischen Elektrochemie, v. 1, pt. 3, ed. by V. Engelhardt.) Leipzig, Akademische Verlagsgesellschaft, 1933. 448 p., illus., 10x7 in., cloth, 41 rm.; paper, 39 rm A handbook of practical information on electroplating, electrotyping, and electroforming, intended for the electrochemist or engineer who wishes a concise, yet comprehensive review of these subjects.

THEORY of ELASTICITY. (Engineering Societies Monographs.) By S. Timoshenko. N. Y. & Lond., McGraw-Hill Book Co., 1934. 416 p., illus., 9x6 in., cloth, $5.00. Presents the fundamentals of the theory of elasticity with special reference to the needs of the engineer. The presentation considers both 2-dimensional and 3-dimensional problems. The photo-elastic, soap-film, and other experimental methods are included. The book is the third of the series of Engineering Societies Monographs.

THERMODYNAMICS of ELECTRICAL PHENOMENA in METALS. By P. W. Bridgman. N. Y., Macmillan Co., 1934. 200 p., diagrs., 9x6 in., cloth, $3.75. During the past 10 years Professor Bridgman has published a number of papers upon interrelations of a thermodynamic character between various electrical properties of metals. The substance of these papers, with some extensions and added relations, is now presented in this volume, which attempts a more or less systematic application of classical thermodynamics to those electrical phenomena amenable to thermodynamic treatment.

WAVE MECHANICS: Advanced General Theory. By J. Frenkel. Oxford (Eng.), Clarendon Press; N. Y., Oxford Univ. Press, 1934. 524 p., tables, 10x6 in., cloth, $12.00. Continues the comprehensive treatise begun with the publication in 1932, of the author's "Wave mechanics: elementary theory." This volume is devoted to the mathematical development of the ideas underlying the new mechanics, to connecting it with classical mechanics and constituting it a complete self-supporting theory.

ELECTRONS at WORK, a Simple and General Treatise on Electronic Devices, Their Circuits and Industrial Uses. By C. R. Underhill. N. Y. and Lond., McGraw-Hill Book Co., 1933. 354 p., illus., 9x6 in., cloth, $3.00. A comprehensive survey of electronics, written without mathematics or undue use of technical language. The fundamental principles and the ways in which the various tubes and cells function are clearly explained; and the applications of electronic devices in industry and biology are indicated in detail. Useful to those who wish to understand these devices or are interested in their industrial uses.

AIR CONDITIONING. 2 vol. By S. R. Lewis. Scranton, Pa., Intl. Textbook Co., 1933. Illus., 8x5 in., lea., v. 1, $1.65; v. 2, $2.00. The subject of air conditioning is presented without complicated mathematics, practical methods being emphasized. The physics of air conditioning, equipment, refrigeration, heat transmission through buildings, piping and duct design, and temperature control are discussed, and a final section deals with design.

AMERICAN INVENTORS. By C. J. Hylander. N. Y., Macmillan Co., 1934. 216 p., illus., 8x5 in., cloth, $3.00. The stories of 19 well-known inventors, from Franklin and Fitch to Jenkins and De Forest, are briefly related in this book, which is intended for boys of a mechanical turn of mind. In spite of their brevity, the sketches are pleasant reading.

BOOK of SCIENTIFIC DISCOVERY, How Science Has Aided Human Welfare. By D. M. Turner. Lond., Bombay & Sidney, G. G. Harrap & Co., 1933. 259 p., illus., 9x6 in., cloth, 7s 6d. This is a readable history of science, intended for popular reading and for use as a textbook. The development of science since the Middle Ages is outlined, with emphasis upon its effect upon society and human welfare. The work is attractively illustrated.

ELEMENTS OF RADIO COMMUNICATION. By J. H. Morecroft. 2 ed. N. Y., John Wiley & Sons, 1934. 286 p., illus., 9x6 in., cloth, $3.00. Aims to provide a sound, thorough course in a-c theory and its applications to radio communications for those without the preparation or the time called for by the author's "Principles of Radio Communication." Thoroughly revised.

ENGLISH for ENGINEERS. By S. A. Harbarger. 3 ed. N. Y. and Lond., McGraw-Hill Book Co., 1934. 314 p., 8x5 in., cloth, $2.00. Designed to give the engineering student a good, practical command of the language for letter writing and for preparing reports and technical articles. At the same time cultural reading is not overlooked, and sensible suggestions are given to guide the beginner.

EXPLORING the UPPER ATMOSPHERE. By D. Fisk, with introduction by H. L. Brose. N. Y., Oxford Univ. Press, 1934. 166 p., illus., 8x5 in., cloth, $1.75. A popular description, for nontechnical readers, of recent developments in stratospheric physics. Describes the investigations of Professor Piccard and others by means of balloons and discusses sound as an explorer, ultraviolet rays and their discovery of the ozone layer, the paths of radio waves, polar lights, and cosmic rays.

LOUD SPEAKERS, Theory, Performance Testing and Design. By N. W. McLachlan. Oxford (Eng.), Clarendon Press; N. Y., Oxford Univ. Press, 1934. 399 p., illus., 10x6 in., cloth, $13.50. An advanced, fairly complete treatment of the theory and practice of loud speakers. The first part is devoted to an analysis of the theoretical problems of speaker design, and in the second part the theory is applied practically.

ROYAL TECHNICAL COLLEGE JOURNAL Vol. 3, Pt. 2, January, 1934, p. 205–334. Glasgow, Royal Technical College. Illus., diagrs., charts, tables, 10x7 in., paper, 10s 6d. Devoted to recording research work by the staff and senior students of the College. Papers in this number include: An example of magnetic aging, the determination of the moisture content of wood, 2 applications of the thin conical wall theory, parabolic weirs, viscous effects in dynamometer belts, electrode systems for dielectric loss measurements, and some notes on the ignition coil.

SHORT WAVE WIRELESS COMMUNICATION. By A. W. Ladner and C. R. Stoner. 2 ed N. Y., John Wiley & Sons, 1934. 384 p., illus., diagrs., charts, tables, 9x6 in., cloth, $3.75. A self-contained presentation, largely nonmathematical in character and designed to meet the needs of professional engineers and radio operators, as well as amateurs. Enlarged by the addition of new material.

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Industrial Notes

Summary of Real Property Inventory

THE vast potential market for electric, gas, and other lighting, cooking, and refrigeration equipment in the United States is reflected in the statistics recently made available for 55 of the 64 cities specially enumerated under the real property inventory recently taken by the U.S. Bureau of Foreign and Domestic Commerce, under the supervision of Daniel E. Casey. In the following table, compiled in the statistical division by Alanson D. Morehouse, chief statistician of the real property inventory unit of the U.S. Bureau of Foreign and Domestic Commerce, are shown the number of structures and dwelling units in these cities, with the number and percentage of dwelling units using or not using electricity for lighting and cooking, and the number and percentage of homes provided with mechanical refrigeration, distributed by geographical divisions and cities. (Preliminary figures, July 20, 1934.)

		Dwelling Units					
			Lighting Facilities		Cooking Facilities		
Geographic Divisions and Cities	No. of Structures	No. of Dwelling Units	Using Electricity	Not Using Gas or Electricity	Using Electricity	Not Using Gas or Electricity	No. With Mechanical Refrigeration
Totals for 55 Cities	1,114,033	1,421,096	1.253,700 (88.7%)	160,380 (11.3%)	49,955 (3.5%)	431,406 (30.3%)	238,242 (16.8%)
Geographic Divisions							
New England	50,435	85,417	82,498 (96.6%)	2,351 (2.8%)	1,293 (1.5%)	29,482 (34.5%)	11,188 (13.1%)
Middle Atlantic	117,731	176,871	170,608 (96.5%)	5,300 (3.0%)	619 (0.4%)	19,016 (10.8%)	26,243 (14.8%)
East North Central	99,677	117,858	111,590 (94.7%)	5,618 (4.8%)	1,654 (1.4%)	21,148 (17.9%)	18,788 (15.9%)
West North Central	144,407	174,087	163,670 (94.0%)	9.924 (5.7%)	1,149 (0.7%)	41,430 (23.8%)	35,140 (20.2%)
South Atlantic	127,615	166,291	128,482 (77.3%)	36,138 (21.7%)	4,174 (2.5%)	77,563 (46.6%)	30,998 (18.6%)
East South Central	129,220	154,447	103,185 (66.8%)	50,908 (33.0%)	1,588 (1.0%)	102,333 (66.3%)	16,458 (10.7%)
West South Central	181,256	215,827	175,555 (81.3%)	39,248 (18.2%)	575 (0.3%)	44,963 (20.8%)	37,147 (17.2%)
Mountain	89,309	114,828	108,668 (94.6%)	5,739 (13.8%)	5,796 (13.8%)	51,790 (45.1%)	21,870 (19.0%)
Pacific	174,383	215,470	209,444 (97.2%)	5,154 (2.4%)	23,107 (10.8%)	43,681 (20.3%)	40,410 (18.8%)
New England							
Burlington, Vt.	4,252	6,618	6,465 (97.6%)	123 (1.8%)	217 (3.3%)	1,370 (20.7%)	1,068 (16.1%)
Nashua, N. H.	4,646	7,969	7,595 (95.3%)	259 (3.2%)	23 (0.3%)	2,740 (34.3%)	1,156 (14.5%)
Portland, Me.	10,475	19,689	18,858 (95.7%)	533 (2.7%)	294 (1.4%)	5,868 (29.8%)	2,884 (14.6%)
Waterbury, Conn.[1]	16,060	30,304	29,409 (97.0%)	804 (2.6%)	181 (0.6%)	5,280 (17.4%)	3,977 (13.1%)
Worcester, Mass.[2]	15,002	20,837	20,171 (96.8%)	632 (3.0%)	578 (2.7%)	14,224 (68.2%)	2,103 (10.0%)
Middle Atlantic							
Binghamton, N. Y.[1]	21,757	32,409	31,660 (97.6%)	692 (2.1%)	329 (1.0%)	5,703 (17.6%)	4,417 (13.6%)
Erie, Pa.[1]	25,194	33,179	32,424 (97.7%)	638 (1.9%)	32 (0.1%)	2,062 (6.2%)	3,052 (9.2%)
Syracuse, N. Y.[3]	35,764	56,340	55,364 (98.2%)	751 (1.3%)	164 (0.03%)	2,105 (3.7%)	10,799 (19.1%)
Trenton, N. J.[1]	26,557	42,802	39,863 (93.1%)	2,535 (5.9%)	36 (0.1%)	6,284 (14.6%)	6,298 (14.7%)
Williamsport, Pa.	8,459	12,141	11,297 (93.0%)	684 (5.6%)	58 (0.5%)	2,862 (23.5%)	1,677 (13.8%)
East North Central							
Decatur, Ill.	14,662	16,407	15,164 (92.4%)	1,081 (6.5%)	28 (0.2%)	3,278 (19.9%)	2,330 (14.2%)
Kenosha, Wis.[1]	11,058	13,843	13,398 (96.7%)	411 (2.9%)	98 (0.7%)	2,036 (15.0%)	1,743 (12.6%)
Lansing, Mich.	18,144	20,815	20,458 (98.3%)	330 (1.6%)	1,055 (5.0%)	4,030 (19.7%)	2,987 (14.3%)
Peoria, Ill.[1]	31,206	35,862	33,619 (93.7%)	2,138 (5.9%)	150 (0.42%)	7,405 (20.6%)	7,363 (20.5%)
Racine, Wis.[1]	15,565	20,253	19,489 (96.2%)	700 (2.4%)	228 (1.1%)	2,818 (13.0%)	2,917 (14.4%)
Zanesville, Ohio	9,042	10,678	9,462 (88.6%)	958 (8.9%)	95 (0.9%)	1,481 (13.8%)	1,448 (13.6%)
West North Central							
Des Moines, Iowa[1]	37,341	44,858	42,594 (94.9%)	2,219 (4.9%)	233 (0.6%)	9,129 (20.3%)	7,780 (17.3%)
Fargo, N. Dak.	5,209	7,467	7,276 (97.4%)	129 (1.7%)	15 (0.2%)	1,202 (16.1%)	1,929 (25.8%)
Lincoln, Neb.	18,780	23,242	22,550 (97.0%)	554 (2.4%)	102 (4.3%)	4,403 (18.9%)	6,403 (27.5%)
Sioux Falls, S. Dak.	7,561	9,240	9,028 (97.7%)	192 (2.0%)	165 (1.7%)	1,618 (17.5%)	1,701 (18.4%)
Springfield, Mo.	14,801	16,200	13,880 (85.7%)	2,202 (13.6%)	109 (0.7%)	7,809 (48.2%)	2,783 (17.1%)
St. Joseph, Mo.	16,686	19,932	18,350 (92.0%)	1,540 (7.7%)	251 (1.2%)	7,348 (36.8%)	3,833 (19.2%)
Topeka, Kan.	16,300	19,092	18,079 (99.7%)	995 (5.2%)	61 (0.32%)	3,169 (16.6%)	3,216 (16.8%)
Wichita, Kan.[1]	27,729	34,056	31,913 (93.7%)	2,093 (6.1%)	213 (0.7%)	6,752 (19.8%)	7,495 (22.0%)
South Atlantic							
Asheville, N. C.	10,833	12,584	10,139 (80.5%)	2,434 (19.3%)	815 (6.4%)	9,498 (75.4%)	2,013 (15.9%)
Charleston, S. C.	10,759	17,911	8,926 (49.8%)	8,950 (49.9%)	182 (1.0%)	11,414 (63.7%)	1,637 (9.1%)
Columbia, S. C.	10,000	12,188	7,882 (64.6%)	4,102 (33.6%)	24 (0.2%)	7,168 (58.8%)	1,895 (15.5%)
Frederick, Md.	2,635	3,785	3,321 (87.7%)	437 (11.5%)	170 (4.5%)	1,896 (50.0%)	764 (20.1%)
Greensboro, N. C.	11,000	12,061	9,977 (82.7%)	2,050 (16.9%)	352 (2.9%)	7,731 (64.0%)	2,214 (18.4%)
Hagerstown, Md.	5,035	8,149	7,706 (94.6%)	394 (4.8%)	265 (3.2%)	3,504 (42.9%)	1,592 (19.5%)
Richmond, Va.[1]	41,201	54,957	43,697 (79.5%)	11,121 (10.2%)	1,924 (3.5%)	24,257 (44.1%)	14,102 (25.6%)
Wheeling, W. Va.[1]	36,152	44,656	36,834 (82.5%)	6,650 (14.9%)	442 (1.0%)	12,095 (27.0%)	6,781 (15.2%)
East South Central							
Birmingham, Ala.[1]	82,704	101,721	67,548 (66.4%)	34,105 (33.5%)	942 (1.0%)	64,749 (63.6%)	11,198 (11.0%)
Jackson, Miss.	9,563	11,422	7,307 (63.9%)	4,075 (35.7%)	3 (0%)	5,219 (45.7%)	1,155 (10.1%)
Knoxville, Tenn.[1]	29,188	32,275	22,161 (68.7%)	10,018 (31.0%)	629 (1.9%)	26,156 (81.0%)	3,524 (10.9%)
Paducah, Ky.	7,765	9,029	6,169 (68.3%)	2,710 (30.0%)	14 (0%)	6,209 (68.7%)	581 (6.4%)
West South Central							
Baton Rouge, La.	6,951	7,692	5,379 (69.9%)	2,142 (27.8%)	10 (0.1%)	3,232 (42.0%)	999 (12.9%)
Oklahoma City, Okla.[1]	40,093	49,714	43,135 (86.8%)	6,114 (12.3%)	103 (0.2%)	6,470 (13.0%)	11,795 (23.7%)
Dallas, Texas[1]	66,813	83,628	70,972 (84.8%)	12,507 (14.9%)	298 (0.4%)	17,187 (20.5%)	13,894 (16.6%)
Austin, Texas	12,849	14,407	11,321 (78.6%)	3,052 (21.2%)	41 (0.3%)	5,043 (35.0%)	2,166 (15.0%)
Little Rock, Ark.	25,161	27,792	20,089 (72.3%)	7,630 (27.4%)	50 (0.2%)	9,607 (34.6%)	4,667 (16.8%)
Wichita Falls, Tex.	9,667	10,722	8,968 (83.6%)	1,735 (16.2%)	67 (0.7%)	1,639 (15.3%)	1,418 (13.2%)
Shreveport, La.	19,722	21,872	15,691 (71.7%)	6,068 (27.7%)	6 (0%)	1,785 (8.1%)	2,208 (10.0%)
Mountain							
Albuquerque, N. Mex.	6,458	7,820	6,865 (87.8%)	928 (11.8%)	64 (0.9%)	2,996 (38.3%)	1,124 (14.4%)
Boise, Idaho	5,167	6,477	6,362 (98.2%)	210 (3.2%)	1,917 (29.6%)	3,169 (48.9%)	1,307 (20.1%)
Butte, Montana	7,358	10,727	10,540 (98.3%)	126 (1.1%)	1,098 (10.2%)	6,394 (59.6%)	991 (9.2%)
Casper, Wyoming	4,270	5,600	5,108 (91.2%)	477 (8.5%)	31 (0.6%)	673 (12.0%)	813 (14.5%)
Phoenix, Arizona	10,519	14,392	13,182 (91.4%)	1,137 (7.9%)	98 (0.7%)	3,285 (22.8%)	2,909 (20.2%)
Pueblo, Colo.	10,882	12,723	11,539 (90.7%)	1,033 (8.1%)	1,464 (11.5%)	6,465 (50.8%)	1,593 (12.5%)
Reno, Nev.	4,652	6,194	5,953 (96.1%)	121 (1.9%)	1,330 (21.4%)	2,973 (48.0%)	1,360 (21.9%)
Salt Lake City, Utah[1]	37,858	48,175	47,088 (97.7%)	1,027 (2.1%)	9,717 (20.1%)	24,078 (49.9%)	11,479 (23.8%)
Santa Fe, N. Mex.	2,145	2,720	2,031 (74.7%)	680 (25.0%)	77 (2.9%)	1,757 (64.6%)	294 (10.8%)
Pacific							
Portland, Oregon[1]	93,526	115,270	112,120 (96.3%)	2,648 (2.2%)	21,266 (18.4%)	34,383 (29.8%)	23,665 (20.5%)
Sacramento, Calif.[1]	28,292	36,505	35,144 (96.2%)	1,126 (3.0%)	1,406 (3.8%)	5,504 (15.0%)	6,408 (17.5%)
San Diego, Calif.[1]	52,565	63,695	62,180 (97.3%)	1,380 (2.1%)	435 (0.7%)	3,794 (5.9%)	10,337 (16.2%)

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Minerallac Electric Co., Chicago

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TOWERS, TRANSMISSION
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TRANSFORMERS

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Kerite Ins. Wire & Cable Co., New York
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General Cable Corp., New York
Kerite Ins. Wire & Cable Co., New York
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